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Catarina Johansson

Attached algal vegetation in running waters of Jämtland, Sweden

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Abstract

Johansson, C. 1982, *Attached algal vegetation in running waters of Jämtland, Sweden.* Acta phytogeogr. suec. 71, Uppsala. 84 pp.

The study deals with the quantitative analysis of attached algal vegetation in the running waters of Jämtland. Algae were collected and 14 environmental parameters measured or estimated in 1975–1976. The total dataset of 501 streams and 314 algal species was treated with numerical methods including cluster, component and discriminant analysis and with statistical tests including the Kolmogorov statistics. This resulted in the ecological characterization of each algal species found (see further Johansson 1982, in prep.) and the establishment of 16 main types of algal communities, including their ecological conditions and the distinction of indicator species for altitude, size of stream, temperature, pH, conductivity, calcium content, colour, insolation, surrounding vegetation and current velocity.

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1. Introduction

1.1 Aims

The main aim of this study was to find the extent to which local attached algal vegetation or single algal taxa can be used as indicators for certain environmental conditions in running waters, both as regards abiotic conditions in the streams and biotic conditions along their borders. Algal vegetation will be treated here both in terms of algal communities and of individual indicator species.

The province of Jämtland (Fig. 1) in the middle of Sweden was chosen as research area because it provides a large variation in bedrock and vegetation types. Here, within a rather limited area, a great variety of running waters (Figs. 2–5) with communities of attached algae can be studied. The area has mountains and lowlands, various bedrock types, including limestone, and different types of surrounding woodland.

1.2 Earlier Swedish research on attached algae in running waters

The first relevant studies are those of Kylin (1912) on the red algae *Batrachospermum* and *Sirodotia* from many parts of Sweden. Fontell (1917) investigated freshwater diatoms from northern parts of Jämtland. Extensive works from the northern parts of Sweden containing both attached and plankton algae are those from the Sarek region by Strøm (1923) and Hustedt (1924). Booberg (1930) studied the algae in the Gisselås mire, Jämtland. Mainly central parts of Sweden were investigated as regards freshwater Phaeophyceae, Florideae and Zygnemales by Israelson (1938, 1942, 1949). He classified the Swedish running waters into an oligotrophic type called *Zygnema* streams, and a eutrophic one, *Vaucheria* streams. The Abisko area in the northernmost part of Sweden was taxonomically and ecologically investigated by Hustedt (1942). He analyzed samples both from lakes and streams and registered chemical and physical parameters. The most useful work for comparison is the very thorough investigation of the diatoms in the lakes of the Långan river system in Jämtland by Quennerstedt (1955). A comprehensive study of both planktic and attached algae in the northern part of Sweden was carried out by Skuja (1964). The major rivers of northern Sweden have been briefly described by Quennerstedt (1965) with respect to both macrophytic and algal vegetation. Experimental studies on migration periodicity of unicellular algae were carried out by Müller-Haeckel (1976). She studied drift algae, i.e. sessile algae detached from their substrates, in a stream flowing into the River Stora Lule älv, the Kaltisjokk, using exposed microscope slides both in aquaria with flow-through and in the stream itself. These algae drift down the stream after their cell fission and form a new colony on another substrate. Backlund & Renberg (1973) worked partly in the same project. Both Kaltisjokk and Verkeån, the latter located in Scania, southern Sweden, were studied by Klasvik (1974), who followed the development in Verkeån during a whole year. Lake Hjälmaren in central Sweden and its tributaries were investigated with respect to the attached algal vegetation by Kronborg (1975). Some streams in central Sweden have been classified by Stjerna-Pooth (1978) as regards benthic communities. Berzinš (1979) studied both periphyton and plankton in Ybbarbsån, southern Sweden.

A survey of literature on attached algal vegetation in running waters also from parts of the world outside Scandinavia was carried out by Johansson et al. (1977).

1.3 The investigation area

1.3.1 Bedrock geology

The following geological information is summarized from Högbom (1920) and Lundqvist (1969).

The northern and western parts of the province, apart from a small part in between, consist of alpine schists (Fig. 6). The eastern part consists mainly of granites and gneisses (Fig. 7) and the southernmost part mainly of quartzites and sparagmites (Fig. 8). The area in between consists mainly of Cambro-Silurian rocks (Fig. 9), especially around Lake Storsjön.

The influence of bedrock upon the fertility of the soil is indicated with Eklund's (1952) scale (Fig. 10). Granites and gneisses form very resistant bedrocks, which produce moraines (tills) of low fertility. The influence of the schists on vegetation is somewhat more

Fig. 1. Map of the 503 stations sampled in 1975–1976 in Jämtland. Names and descriptions of the stations are given in Johansson (1982, in prep.).

Fig. 2. Montane streams a) The Kruptje-stream near Mt. Anaris. b) The Leipikälv, on alpine slate, in the NW corner of Jämtland.

Fig. 3. The Bakvattsbäck, a stream surrounded by dense spruce forest.

Fig. 4. The Björkbäck, a stream surrounded by both coniferous and deciduous trees.

Fig. 5. A "moss-rivulet" flowing off Mt. Skraupvalen (near Mt. Anaris). Nearly all stones in the stream were covered by the hepatic *Marsupella aquatica*.

favourable and particularly the soft schists produce good soils. Quartzites and sparagmites are hard bedrocks, which produce tills of low fertility. Amphibolites and other greenstones also form tough bedrocks which however have a rather favourable influence on the soil. The Cambro-Silurian bedrocks contain both sandstones and greywackes rich in clay which, like the limestones and alun slates, produce very favourable soils.

The most important morphological regions in the province are, according to Lundqvist (1969 p. 18, Fig. 4), mountain region, premontane region, undulating hilly Norrland terrain, monadnock plains of Central Jämtland, and the great nappe (Fig. 11).

1.3.2 Soil deposits

Moraine (till) is the soil directly deposited by the land ice. Its quality depends upon the bedrocks from which it was created. The percentage of the different sorts of bedrock material in the till is the basis for its different types, and in Jämtland the latter coincide closely with the bedrock regions described above. Other types of soil deposits are glacio-fluvial sediments, marine and lake sediments, sub-morainic sediments, aeolian sediments, alluvial sediments, peat deposits, upfreezing and solifluction soils.

1.3.3 Watercourses

The drainage in Jämtland runs from NW to SE, as is the case throughout Norrland where the normal courses are towards the east, southeast or south. The drainage areas are shown in Fig. 12. The province lies within four major water catchments, namely the Ljungan, its tributary Gimån, the Indalsälven, and the Ströms Vattudal. The total area covered by lakes in the region is about 10 %. Lake Storsjön is the

Fig. 6. Percentages of caledonian schists in the till (from Lundqvist 1969, Fig. 10).

Fig. 7. Percentages of granites, gneisses and quartz in the till (from Lundqvist 1969, Fig. 9).

Fig. 8. Percentages of quartzites and sparagmites in the till (from Lundqvist 1969, Fig. 11).

Fig. 9. Percentages of unmetamorphosed Cambro-Silurian rocks in the till (from Lundqvist 1969, Fig. 13).

Fig. 10. Influence of the bedrock upon the fertility of the soil where 5 has the most favourable effect, and 1 the least. The values are based on Eklund's (1952) scale (redrawn after Lundqvist 1969, Fig. 74).

Fig. 11. The most important morphological regions in the County of Jämtland. Regions: 1 mountain region, 2 premontane region, 3 undulating hilly Norrland terrain, 4 monadnock plains of Central Jämtland, 5 boundary of great nappe (redrawn after Lundqvist 1969, Fig. 4).

largest lake. Most of the large and medium-sized lakes are dammed as hydro-electric reservoirs.

The Ljungan drains only a small part of southernmost Jämtland. It has been regulated for waterpower except in its uppermost part within Härjedalen. The unexploited Gimån consists of short streams which flow in small rapids with big boulders between large lakes. The catchment area of the Indalsälven covers half of Jämtland. The Enan and the Handölan rivers, which both originate in the Sylarna Mts., are regarded as its sources. The main tributaries are the Duved river, the Järpströmmen, Långan, Hårkan, and Ammerån. The falls and rapids located above Lake Storsjön are: Handölan falls (110 m), Tännforsen (38 m), Rista falls (20 m), Äggforsen (13.5 m) and Storbo falls (27 m). All these are unexploited. Large rapids below Lake Storsjön are: Hissmoforsen (15 m), Näverede rapids (13.5 m), Krångede rapids (58 m) and Hammarforsen (16 m) all of which are exploited for hydro-electric power. Several of the tributaries have also been partly exploited, but the Ammerån system is still unaffected.

The valley system of Indalsälven has many morphological peculiarities. Some of the tributaries come from very flat U-shaped valleys such as the Lunndörren valley in a mountain complex and the Ekorrdörren area. The Storlien pass, constituting the watershed between the Atlantic and the Baltic, is also a typical U-valley.

Another essential feature is the distribution of the rocks and their resistence to weathering. The large rivers mostly flow towards the southeast as they are

Fig. 12. Watercourses in the County of Jämtland.

Table 1. Nutrients summarized from 41 alpine lakes in Jämtland (1975). (from the County Administration, Östersund)

	μg NO_3-N/l	(μg Tot.N/l)	(μg PO_4-P/l)	μg Tot. P/l
$\bar{x}$	8.5	223	4.5	7.2
range	5–65	50–1730	2–14	4–18

Table 2. Chemical measurements in 60 lakes in Jämtland (1975). (County Administration, Östersund)

	pH	Cond. μS	A mekv/l	NO_3-N μg/l	Tot. P μg/l
$\bar{x}$	7.1	43	300	57	5
stand.dev.	0.4	34	340	38	3

The seasonal variation in water discharge in most parts of Jämtland may be characterized as an "inland regime", and in alpine parts as an "alpine regime". The seasonal variations are described with an index system (H_1 = snowmelt, H_2 = an intermediate form with high water both in spring and autumn, L_1 = winter low water) as follows (after Falkenmark 1979):

	winter	spring	summer	autumn
H_1L_1 alpine regime	*L*	*H*	–	–
H_2L_1 inland regime	*L*	*H*	–	*H*

The seasonal variation in water discharge naturally influences the available water supply. It was below normal in unaffected watercourses in the whole of Sweden in the investigation years 1975 and 1976 and in some places far below normal, with the exception of the central parts of the mountain chain.

A summary of the chemical composition of the waters in Jämtland based on chemical measurements in watercourses and lakes with data from Hugo Sjörs (pers. comm.), the County Administration, Östersund (pers. comm.) and Johansson (1979 a, b) is given in Tables 1–5. Parameters which refer to surroundings have been measured in this study and distribution curves for 10 of the 12 parameters are drawn (Fig. 13).

strong enough to maintain their primary courses in preglacial valleys over the harder rocks. Smaller streams do not have this capacity and may flow in any direction. The large rivers have created so-called break-through valleys by penetrating rock material such as gneiss, porphyry and amphibolite. Examples are the Åre, Offerdal, Landsjön and Åkersjö valleys.

The Ströms Vattudal constitutes a nearly continuous lake system. The altitudinal difference along its course through Jämtland is only 35 m, of which 11 m is in the Gäddede rapids in the Frostviken area. Among the southern tributaries is the R. Hällingsån, famous for its rapids and canyon. The river has eroded a 600 m long and 60 m deep gorge in the rock. The largest tributaries from the north are Storån and the outflow from Lake Jormvattnet, and there are several other outlets from lakes.

1.3.4 Climate

The province of Jämtland is on the border between two climatic regions, the atlantic and the boreal. Three meteorological stations for the whole of

Table 3. Chemical measurements from 8 streams in Jämtland, August 1978 (*one stream with very high value not included).

	NO_3-N	Tot. P
$\bar{X}$	23 (300)*	9.2
range	8-40 (300)*	5-15

Table 4. Mean values and range of some chemical parameters from 503 streams in Jämtland.

	Temp. (°C)	cond. (μS)	pH	mg Ca/l	Colour (mg Pt/l)
$\bar{X}$	10.5	77	7.0	29	38
range	1-16	<10-240	5.3-7.5	<5-125	<10-160

Table 5. pH and conductivity from 26 stations in 15 different streams measured in 1961. (Sjörs pers.comm.)

	pH	cond. (µS)
$\bar{X}$	7.55	111
range	6.5-8.1	15-284

Table 6. Monthly temperature and precipitation measured at Frösön in the summers of 1975 and 1976. (SMHI 1975-1976)

	Temperature				Precipitation			
	1975	(1931-60)	1976	(1931-60)	1975	(1931-60)	1976	(1931-60)
June	10.4	11.3	11.2	12.2	61	69	67	69
July	14.5	14.7	14.1	15.3	21	77	83	77
August	13.9	13.4	13.7	13.5	30	74	17	74
Sept.	9.4	8.9	5.4	8.6	69	51	41	51

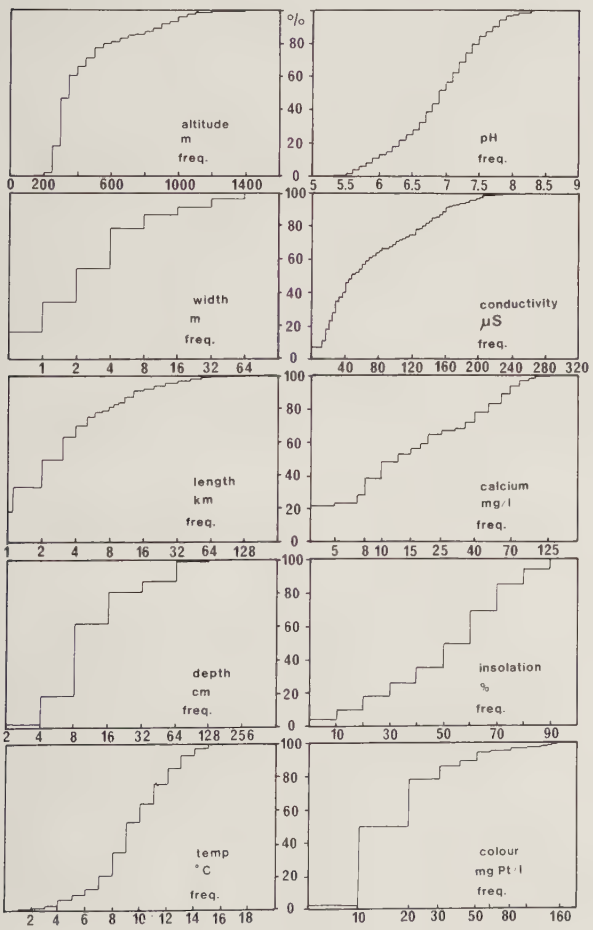


Fig. 13. Cumulative distribution curves for 10 of the measured ecological parameters, based on 501 stream stations.

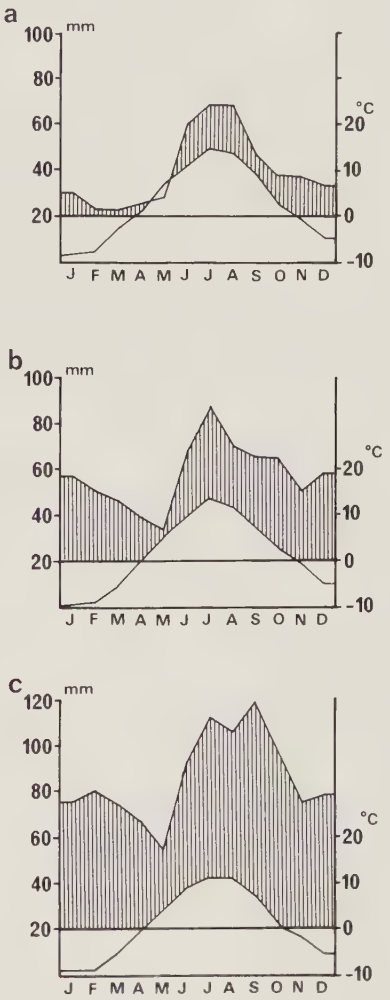


Fig. 14. Normal climate (average of 1931–1960) at three different meteorological stations in Jämtland. a) Frösön, located in Central Jämtland, 352 m a.s.l., mean annual temperature (T_a) of 2.9°C, mean annual precipitation (P_a) of 478 mm. b) Gäddede, located in NW Jämtland, 310 m a.s.l., $T_a = 1.8$°C, $P_a = 682$ mm. c) Storlien, located in W Jämtland, 630 m a.s.l., $T_a = 1.0$°C, $P_a = 1025$ mm.

Jämtland were chosen to give a picture of precipitation and temperature, namely Frösön airport in Lake Storsjön, Gäddede located in NW Jämtland near the Norwegian border and Storlien located in W Jämtland, where the mountains are not high enough to prevent the Atlantic air moving east. Fig. 14 shows the three climatic diagrams (after Walter & Lieth 1960–1967).

Snow cover lasts for 175–200 days. Small lakes and tarns get covered by ice at the end of October and bigger lakes in November. The monthly temperature and precipitation for the summers of 1975 and 1976 are summarized in Table 6.

1.3.5 Vegetational regions

In order to see whether or not there is a relation between algal communities and vegetational regions the following system of regions was adopted.

Lange (1938) in his flora of Jämtland discerned three distinct regions in Jämtland: the mountain area, the Cambro-Silurian area, and the primary rock area. The mountain area has three of the vegetational regions in which the Scandinavian flora has been divided, the alpine region (regio alpina), the birch region (regio subalpina), and the coniferous region (regio silvatica), while the Cambro-Silurian area and the primary rock area are both within the coniferous region.

The mountain area. Above the timber line the alpine region includes fairly level plateaux as well as ridges and peaks. Only the highest peaks reach the high-alpine belt and are nearly devoid of vegetation except for lichens, mosses and a few vascular plants. Peaks of about 1400 m belong to the mid-alpine belt which has a less sparse vegetation although still poor in species. Characteristic alpine heaths predominate further down, with a dense growth of mainly brushwood and dwarf-shrubs. The dwarf-shrub vegetation contains species such as *Arctostaphylos alpina, Betula nana, Diapensia lapponica, Empetrum hermaphroditum, Loiseleuria procumbens, Lycopodium alpinum, Phyllodoce coerulea, Salix herbacea, Vaccinium myrtillus, V. uligonosum* and *V. vitis-idaea*. Richer types of herbaceous vegetation are fairly frequent, especially on the softer rocks.

Mires are very frequent in lower parts of the alpine region, especially in the western part of the province, where they are maintained by the high summer precipitation. Most of the mires there on sloping ground depend on supply of mineral soil water (fens) but mires not reached by mineral soil water (bogs) exist locally. Parts of a mire where bog and fen exist together, are called mixed mires but are not frequent in the alpine region. The mires are characteristic features of the landscape. Fens, favoured by calcareous soils, are much more common in Jämtland than bogs. The plentiful subsoil water flows through the fens to the watercourses.

The vegetation of the birch region is mainly of dwarf-shrub types but in the meadow-like types of birch woods the flora is rich in species and here the biomass is very high. Parts with a maritime climate, such as those near the Norwegian border, are renowned for their beautiful vegetation. Species like *Aconitum septentrionale, Crepis paludosa, Bartsia alpina, Lactuca alpina*, and *Stellaria nemorum* are frequent. In the subalpine region, as in the alpine region, the phanerogamous vegetation in the watercourses is very sparse. The coniferous region covers very large areas and extends to about 650–800 m. The dominating tree is spruce, followed by birch (*Betula pubescens*). Pine woods occur locally. Mires are more frequent in the birch and coniferous regions than in the alpine region. Both fens, mixed mires, and bogs occur.

The Cambro-Silurian area. The region is slightly hilly or nearly flat with spruce forests, often with a rich undergrowth, mires and arable land. The limestone bedrock creates some vegetation types, which only occasionally have counterparts in the primary rock area, i.e., rich swamp forests and calcareous fens. The floristic composition of these vegetation types below slopes and on sloping ground is mainly a result of percolating water with a low temperature in summer and a comparatively high one in winter, preventing soil frost. But there are also fens, mixed mires and bogs on fairly level ground.

The primary rock area. Most of the area (60 %) is covered by coniferous forests. Some parts have numerous lakes. Fields are located mainly on riversides and around lakes. Pine is the dominating tree on sandy soils, whereas on other soils spruce is predominant. The deciduous woods, nearly always secondary, have species like birch (*Betula pubescens* and *verrucosa*), aspen (*Populus tremula*) and grey alder (*Alnus incana*) as dominating trees. Mires are less common and usually smaller than those in the Cambro-Silurian bedrock area, near the latter area often being quite rich, due to calcareous material which was transported eastward and deposited by the inland ice.

1.4 On terms concerning attached algal communities

The term *periphyton* was used by Roll (1939) for all attached organisms on any substrate. He divided it into (1) epiphyton (German: *Aufwuchs*), including all attached single organisms on stable substrate not considering their belonging to communities, and (2) lasion (German: *Bewuchs*) including attached organisms forming real communities. Young (1945) gave the following definition: "By periphyton is meant that assemblage of organisms growing upon free surfaces of submerged objects in water and covering them with a slimy coat." Whitton (1975) treated periphyton as all the various types of algae

growing on surfaces, whether epilithic or epiphytic and firmly or loosely attached.

The term periphyton (literally "at or around a plant") has thus been used in a broader sense, comprising sessile organisms on and around all sorts of substrates.

Aufwuchs is the German word used in literature that closest corresponds to periphyton. Ruttner (1963) includes in this term all those organisms that are fairly firmly attached to a substrate but do not penetrate into it (in contrast to plants rooted in the bottom or certain parasites). Roll (op. cit.) regards Aufwuchs as an earlier step in the development of a lasion.

Benthic algae is used according to Whitton (1975), for algae on all kinds of substrates from sheets of rock to fine silt.

Epiphytes, according to Whitton (1975), are usually regarded as organisms attached rather firmly to a living plant which provides their substratum.

The most adequate concept in this study is *attached algae*, since the algae are really sessile with different types of attaching mechanisms. They usually attach themselves to cliffs and stones but also to pieces of wood and higher aquatic plants (here including mosses).

Sládečková (1962) has thoroughly penetrated the terminology of the attached community.

2. Methods

2.1 Sampling stations

The investigation was carried out during the summers of 1975 and 1976. Algal sampling and environmental measurements were made during the low water discharge period of August and early September. The 501 sampling stations (Fig. 1) were mostly located near roads or mountain tracks and chosen to represent as many different biotopes as possible.

biotopes	*% of all streams studied*
1. glaciers	1
2. alpine heath	11
3. subalpine birch forest	5
4. spruce forest	26
5. pine forest	4
6. coniferous forest	4
7. deciduous forest	4
8. mixed forest	18
9. clear-cut area	6
10. clear-cut area on one side of the stream and coniferous forest on the other	3
11. mire (bog, fen)	6
12. pasture land	4
13. arable land	2
14. built-up land (= villages etc.)	6

2.2 Analysis of attached algae

The attached algae were scraped and brushed off stones, boulders, pieces of wood or macrophytes along a stretch of 40 m. A semiquantitative cover scale with roughly the following percentage degrees was given: 6 = > 75 %, 5 = 60–75 %, 4 = 30–60 %, 3 = 10–30 %, 2 = 3–10 %, 1 = < 3 %. The algae were collected in plexiglass pots and preserved in 4 % formalin. At the laboratory a microscopic examination of the algae was carried out. The diatoms were prepared for microscopical studies by putting a drop of the sample on a glass slide and heating, whereby organic material and the water was removed. The remaining silica shells were embedded in Naphrax with a refraction index of 1.72.

2.3 Environmental analysis

The following topographical and environmental factors were measured at each station (see also Fig. 13):

Altitude in meters above mean sea level.

Width (m), *length* (km) and *depth* (m) of the rivers were estimated in order to reveal whether an alga prefers to live in large, medium-sized or small watercourses; these categories thus combine the three items estimated and may to some extent be regarded as "discharge categories". A small stream probably carries proportionately more algal diaspores and fragments per m^3 of discharge than a large one, since the water surface is small as compared to the area producing diaspores. Large rivers usually pass through lakes, which act as sedimentation basins, so their outflows will contain few sessile algal diaspores (but some plankton algae).

Current velocity is an important factor in running waters. Besides its direct influence on mineral nutrition, the current has a mechanical effect, since the faster it is, the more easily will loosely attached species tend to be washed downstream. Müller-Haeckel (1976) states that algal release from the substrate is an activity of the alga itself. Five different categories of current velocity were used: nearly stagnant or very slight (1), slight (2), moderate (3), strong (4), very strong (5). Observations in Jämtland (Johansson 1979a) gave velocities between 0.10 and 0.97 m/sec. Current velocities of > 5 m/sec reduce the flora to those species which are both very firmly attached and resistant to mechanical damage. The algal vegetation on rocks subject to such conditions is usually dominated by encrusting species, and by species producing filaments with no or only slight branching, e.g. *Lemanea fluviatilis*.

The *size, surface, texture*, and *chemistry* of the substrate may all interact in the influence on distribution and colonization of attached algae in streams. It is

often difficult to distinguish between an effect of texture and one due to the chemical nature. In the present study seven different substrates were noted: cliffs, boulder—stones, stones—gravel, gravel—sand, silt, organic material, and higher plants. About 70 % of all streams had a bottom substrate with boulders and stones.

Temperature was measured in °C and the time of the day was noted. Generally the mean temperature increases from the source to the mouth of the river, although the amplitude of diurnal or even more rapid fluctuations in temperature tend to become less and less. The latter situation is probably the case in large rivers while in small streams the diurnal fluctuation remains rather conspicuous even at the mouth. Temperatures differ between shaded and illuminated parts of the stream over very short distances. Since all measurements were made in August, it is possible to make comparisons, although the mean temperature for all sites was slightly higher than normal due to the warm summers. It is difficult, however, to interpret the effects of light and temperature separately using field observations only, due to their covariation and interaction in photosynthesis.

Conductivity or specific electric conductivity of water increases with increasing content of ionized salts. By definition, specific conductivity of an electrolyte is the reciprocal of the specific resistance of a solution measured between two electrodes 1 cm^2 in area and 1 cm apart, and is expressed in μmhos/cm or μS. The temperature of the electrolyte affects the ionic velocities; the conductivity increases about 2 %/1°C. The international chemical standard reference of 25°C is recommended, even though 18°C or 20°C were widely used in early limnological studies.

pH (except in very acid waters) is governed largely by H^+ ions originating mainly from the equilibrium of dissolved CO_2 and HCO_3^- ions. Jämtland has some calcareous hardwater streams which have pH values above 8. The streams originating in areas of igneous rocks are less well-buffered and more acid, with pH values usually somewhat below 7. The pH was measured with a field pH-meter (Metrohm E 280 A; electrode EA 121 X-A).

Hardness of a water is governed by the contents of calcium and magnesium-ions, primarily in combination with hydrogen carbonate and a few carbonate ions (which give temporary hardness) and with sulfate, chloride, and other anions of strong mineral acids (giving permanent hardness). Dissolved organic colloidal acidoids also contribute to the ionic equilibrium in thermic waters. A field method called Hydro X was used where hardness is given as a figure corresponding to amounts of magnesium and calcium carbonates.

Colour is recorded as the effects of dissolved organic compounds on the absorbtion of light energy. It was measured visually by comparison with standard coloured plates in the range 0—200 mg Pt/l. Dissolved organic compounds, particularly the anions of humic acidoids, not only drastically reduce the transmission of light but also change the absorbtion selectively.

Moss cover was recorded as presence or absence of dense bryophyte vegetation.

Nutrient conditions in the surrounding vegetation types were characterized according to the scale of Arnborg (1964). 1 = poor, 2 = good, 3 = rich, and 4 = very rich. Only the first three were adequate.

Water conditions in the surrounding vegetation were also characterized according to Arnborg (op. cit.) where: 1 = very dry, 2 = dry, 3 = fresh, 4 = moist, 5 = wet.

Encrustation. It was noted whether or not an alga was encrusted with $CaCO_3$. This refers exclusively to *Rivularia haematites* in the present study.

Insolation was estimated since it is known that there is a great difference in the composition of algal vegetation between shaded localities and open ones. The amount of light reaching the algae was estimated as percent (10 % intervals) of the hemisphere of the sky visible from the point of growth. Streams in the alpine region and various other treeless areas thus reached nearly 100 % while streams running through dense spruce forests often got values less than 20 %.

Fourteen types of *surrounding habitat and vegetation* were distinguished (see 2.1). The surrounding vegetation has been included as a parameter since, e.g. algal fragments, spores and heterocysts may occur there and in one way or another be transported to the watercourse.

3. The occurrence of attached algae in Jämtland streams

3.1 General survey

The frequency of all the species composing the whole dataset (501 stations) in relation to occurrence classes is shown in Fig. 15. The form of the curve is roughly lognormal, which implies that the rare (found in fewer than 8 localities) species are most frequent.

Patrick & Reimer (1966) have used this curve to characterize the structure of diatom communities in the US; natural river communities of diatoms are characterized by a large number of species, most of which are represented by a small number of specimens. Communities disturbed in one way or another are recognized by a more flattened curve. Preston (1962) recognized the "Individual Curve" as a lognormal curve with its mode or peak displaced to the right. Similarly, van der Maarel (1971) found a lognormal distribution of vascular plant species over classes of frequency of occurrence in squares of 20 km^2 in the Netherlands. He also compared data from the years 1900 and 1970 and found that the peak of the curve had moved to the left, implying that the number of rare species had increased considerably.

The number of stations in relation to the number of species per stream section (station) is shown in Fig. 16. The mean number of species per station was 9. The distribution curve is almost normal. The left-hand side cannot reach ∞ since the 0 station has 0 species. The right-hand part is flatter with a maximum species number of 25. This seems little in comparison with, e.g. lakes, and if animals are included generally fewer species are found in fast-flowing waters than in slow-flowing and stagnant waters, probably depending on fewer species being specialized to resist strong current velocities.

The cumulative number of sampling stations in relation to number of species was also treated. The aim of the method was to reveal how many stations are necessary to sample to get an almost complete species composition in the area investigated, in this case Jämtland. The present sample of 501 stations was arranged in a random order and the number of new species were recorded in a cumulative diagram. First the semi-logarithmic relation according to the

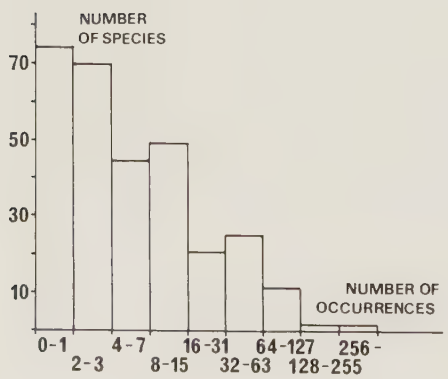


Fig. 15. Number of species ordered in classes including exponentially increasing occurrences. All species (314) from all stations (501) included.

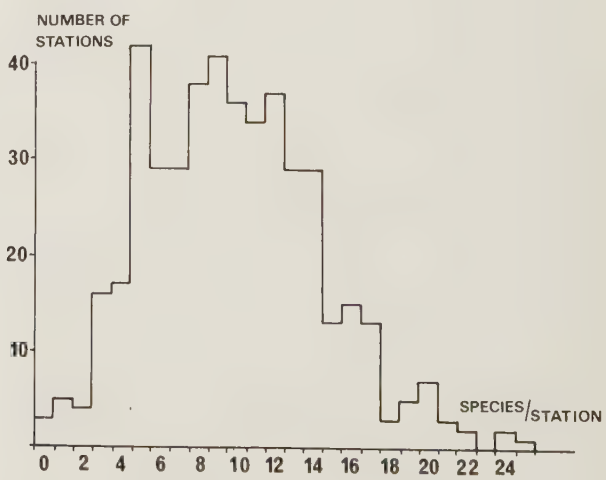
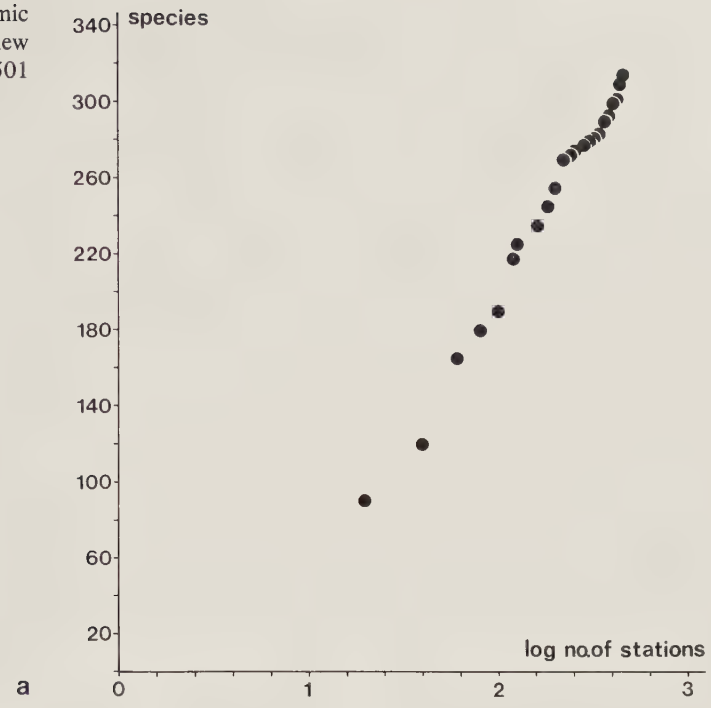
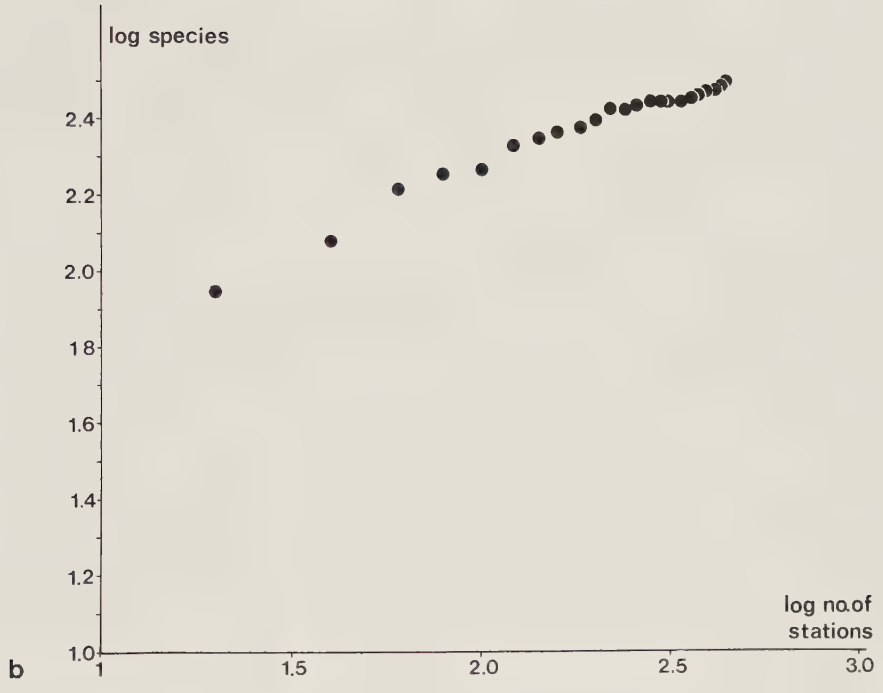


Fig. 16. The number of species in relation to the number of stream sections (= stations).

Fig. 17. a) A semi-logarithmic and b) logarithmic relationship between cumulative number of new species and number of a random order of 501 stations in Jämtland streams.





Fisher-model (Williams 1964) was tested. Du Rietz (1921) constructed species-area curves for the *Parmelia omphalodes* association where species number was plotted against the natural logarithm of the size of samples, thus giving good linear relationship for the largest areas (corresponding to many stations), while the smaller areas (corresponding to few stations) do not fit with the Fisher-model (Fig. 17a, b). A similar pattern was found in the present study. If a straight line is fitted to these observations (number of species from 1 and 5 stations, respectively, not included) the following equation is obtained: $Y = -117 + 160 \log X$, where Y = number of species and X number of stations. A logarithmic relationship with the equation $\log Y = 1.446 + 0.406 \log X$ was obtained. From this it was concluded that the sample of about 500 stations was sufficient even if the curve does not flatten out completely and new species are always found if more stations are sampled.

3.2 Species distribution

A large number of algae, at least of the common species, appear to be worldwide in distribution. Even rare species may be widely distributed. They are locally rare primarily because they require fairly special conditions for active growth. Whitford (1960a) stressed the fact that rare species, or species which are common at only limited times of the year, frequently appear as single, often depauperate cells. Therefore most species are probably available at all times; they flourish when conditions become suitable. Very little is, however, known about the means of dispersal of many algae and consequently we cannot explain how species actually reach the headwaters and are able to remain there despite the total downstream movement to which they must be subjected.

The aim of this data treatment was to clarify ecological preferences of single algal species and also to trace algal species which seem to have nearly equal preferences.

The statistical methods used were (1) establishment of distribution curves according to the Kolmogorov test (for species characterization see Johansson, 1982, an appendix to this volume, and partly included in Chapt. 3.2.2) and (2) discriminant analysis.

3.2.1 Distribution curves according to the Kolmogorov approach

The Kolmogorov approach has been used to see whether stations with one particular species are distributed over the range of an environmental factor (e.g. altitude), according to expectation or not. The presence of a species may be fairly well in accordance with the distribution of all stations = the reference curve (Chapt. 3.2.2). If this is not the case, then the species can be used as an indicator both for that part of the range of the environmental factor where the number of stations is significantly higher and where it is lower than expected.

A confidence band was applied after Kolmogorov (Conover 1971 p. 299). The width and position of the two-sided confidence band is calculated as $S_i(x) \pm w_{1-\alpha}$, where $S_i(x)$ is the empirical cumulative distribution function of the parameter x in streams with the occurrence of alga i and $w_{1-\alpha}$ is the two-sided $(1-\alpha)$ quantile found in Conover (op. cit., p. 397), where n (= number of occurrences) is inserted and the width of the band is given in the table "Quantiles of the Kolmogorov Test Statistic" and the bands for the different levels of significance could be constructed.

In Fig. 18, representing the red alga *Batrachospermum moniliforme*, the confidence band of 80 % is illustrated (the levels of 90 %, 95 %, and 99 % give successively broader bands so that the reference curve falls more frequently inside the band). In the example for calcium content the reference curve is outside the band in most intervals between 10 mg to 40 mg Ca/l which means that the species curve is significantly different from the reference curve at the 80 % level. At the same time it is shown that the species line is located to the right of the reference curve which indicates that *B. moniliforme* prefers higher calcium contents than are normally recorded in streams in Jämtland. The reference curve and the species curve both fall inside the confidence band considering length of rivers and pH, implying that no difference could be tested with those parameters.

Results

The results of Table 7 are summarized so that species indicating either the lower or the upper end of the range of environmental factors are taken together. Six types could be distinguished, including the following species, being indicators of environmental parameters.

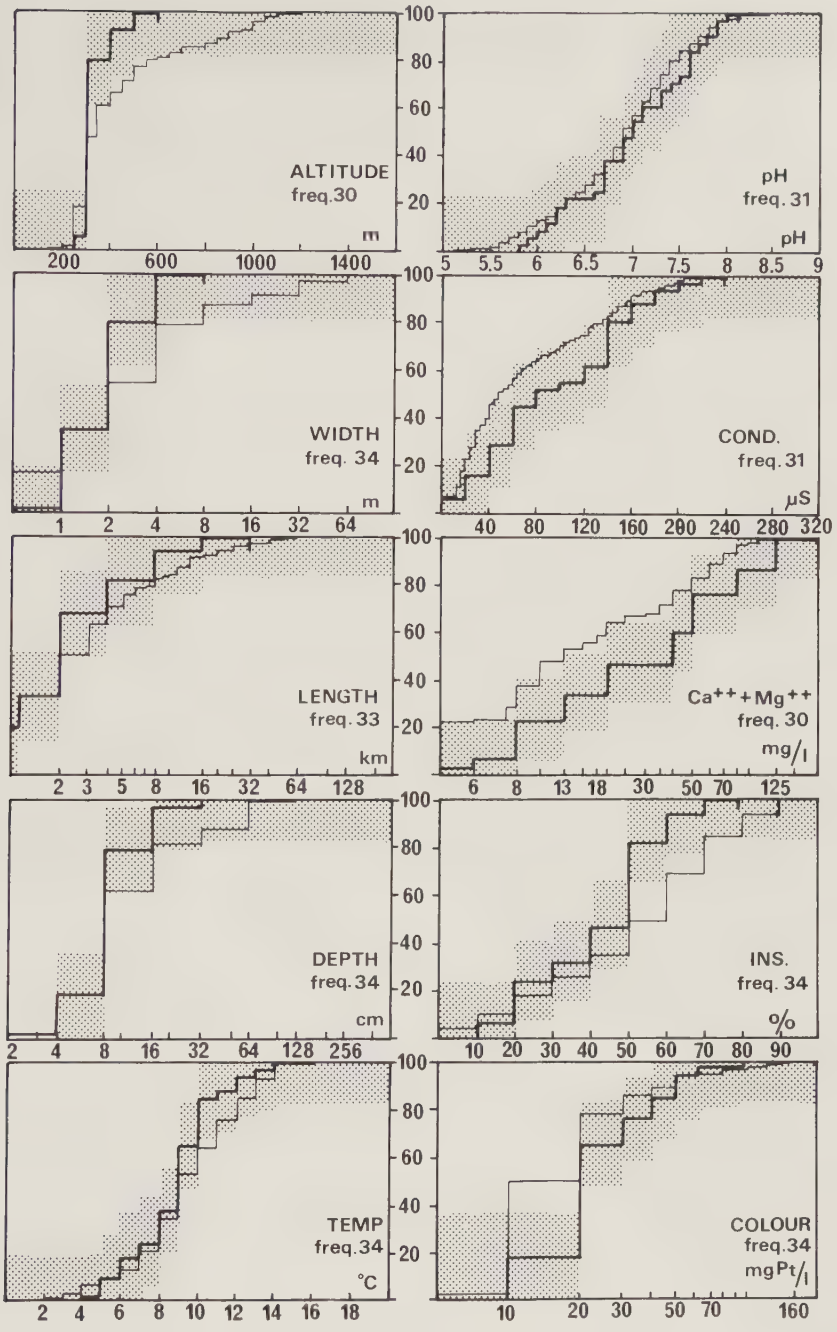


Fig. 18. The cumulative distribution curves and their 80 % confidence bands according to Kolmogorov statistics (Chapt. 3.2.1) on 10 ecological parameters illustrated for the red alga *Batrachospermum moniliforme*.

Table 7. The relation to the reference curve for 112 species, where -/+ indicates values lower or higher than the ref. curve at the significance levels of 95 % (-/*) and 99 % (/**). x indicates that the single species distribution curve shifts from one side of the ref. curve to the other. (A = altitude, W = width, L = length, D = depth of stream, T = temperature, Cond. = conductivity, Ca = calcium content, Ins.= insolation, Col.= colour).

	A	W	L	D	T	pH	Cond.	Ca	Ins.	Col.
Red algae										
Batrachospermum moniliforme	--	-							--	**
Lemanea fluviatilis				--						
Blue-green algae										
Stigonema mamillosum	**	**			**	--	--	--	**	
Tolypothrix penicillata						--	-	--		
Tolypothrix saviczii					**			-	**	
Rivularia biasolettiana		**			*		--	--		
Rivularia haematites						**	**	**		
Green algae										
Tetraspora gelatinosa						--	--	--		
Ulothrix zonata	-						-			
Draparnaldia glomerata					-	-	-	-		
Oedogonium sp. 1					**				**	
Oedogonium sp. 2		**	*				-			
Oedogonium sp. 3	-	**	*	**	*			-		
Bulbochaete spp.							-	-		
Chaetophora glomerata						**				
Zygnema a	**								*	
Zygnema b		**		*	**		--	--	**	
Zygnema c						-				
Mougeotia a			-							
Mougeotia c						-		-		
Mougeotia e		*	**							
Spirogyra a		**	*				-			
Spirogyra b					*					
Spirogyra c		*								
Spirogyra d									-	
Vaucheria spp.	-	-	-		--	**	**	**		
Diatoms										
Cyclotella comta	--	**				*				
C. kützingiana			*	**						
C. kütz.v.planetophora	-						-			
Achnanthes minutissima						*	**	**		
Amphipleura pellucida	-						**	**	--	
Anomoeoneis brachysira		*				--	--	--		
A. brachysira v. lanceolata		**			*		-		*	
A. brachysira v. thermalis				**	**				**	
A. exilis						*				
A. zellensis v. linearis			--						*	
Ceratoneis arcus							--			
C. arcus v. linearis	*		--			--	--	--		
Cocconeis placentula v. euglypta	--					**	**	**	-	

Table 7 (contin.)

	A	W	L	D	T	pH	Cond.	Ca	Ins.	Col.
Cymbella aequalis					*					
C. affinis					-	**			**	
C. cesatii					**					
C. cistula					**					
C. cymbiformis							**			
C. delicatula					*					
C. lunata	*				--	--		-		-x
C. microcephala		*			**				*	
C. prostrata						*		*		
C. ventricosa	--		-					-	**	
Diatoma hiemale v.mesodon			-							
D. hiemale f. turgidula	-					**	*	**		
Didymospenia geminata						*				
Epithemia argus	-	*	*	**	**					
Eunotia lunaris	**	--				--			*	
E. pectinalis						--	--	--		
E. pectinalis v. minor	**					--	--	--	*	
E. praerupta		*						--		
Fragilaria capucina						--				
F. construens				*	**					
F. construens v. venter					**	*				
F. intermedia							--	-		
Frustulia rhomboides	**				**		-	-		
F. rhomboides v. saxonica	*					--	--	--	**	
F. rhomboides v. capitata	**		--			-	--	--	*	
Gomphonema acuminatum v. coronata					*					
G. constrictum v. capitata								-		
G. intricatum	--		-							
G. intricatum v. pumila	-				*	**				
G. longiceps v. subclavata f. gracilis					*		*			
Meridion circulare	-		-			**	**	**		-
N. bacillum			-			**	*			
N. cryptocephala	--	-				**	**	**		
N. cryptocephala v. veneta	--					**	*			
N. gracilis						**				
N. radiosa	--				--					**
Nitzschia linearis										*
Pinnularia gibba			-			-	-	-		
P. interrupta								-	*	-
Stauroneis phoenicenteron		*								
Synedra rumpens						--	--	--		
S. ulna	--					**	**	--x		
Tabellaria fenestrata	--	**		**	**		--	--		
T. flocculosa	**	**			*	--			**	

Type 1: High altitude streams with low pH, low conductivity, and low calcium content.

Stigonema mamillosum
Anomoeoneis brachysira
Ceratoneis arcus v. *linearis*
Cymbella lunata
Eunotia lunaris
E. pectinalis
E. pectinalis v. *minor*
Frustulia rhomboides
F. rhomboides v. *saxonica*
F. rhomboides v. *capitata*
Tabellaria flocculosa

Type 2: Low altitude streams with high pH, high conductivity, and high calcium content.

Rivularia haematites
Cladophora glomerata
Vaucheria spp.
Amphipleura pellucida
Cocconeis placentula v. *euglypta*
Diatoma hiemale f. *turgidula*
Gomphonema intricatum v. *pumila*
Meridion circulare
Navicula cryptocephala
N. cryptocephala v. *veneta*
Synedra ulna (calcium excluded)

Type 3: Large deep streams or stream sections.

Stigonema mamillosum
Oedogonium sp. 2
Oedogonium sp. 3
Zygnema b
Mougeotia e
Spirogyra a
Spirogyra c
Cyclotella comta
C. kützingiana
C. kützingiana v. *planetophora*
Anomoeoneis brachysira
A. brachysira v. *lanceolata*
A. brachysira v. *thermalis*
Cymbella microcephala
Epithemia argus
Fragilaria construens
Tabellaria fenestrata
T. flocculosa

Type 4: Shaded lowland streams and stream sections (+ indicates brown water).

Batrachospermum moniliforme (+)
Rivularia haematites
Spirogyra d
Amphipleura pellucida (+)
Gomphonema intricatum

Type 5: Small cold streams

Batrachospermum moniliforme
Vaucheria spp.
Ceratoneis arcus v. *linearis*
Diatoma hiemale v. *mesodon*
Meridion circulare
Pinnularia interrupta

Type 6: Large and warm streams

Stigonema mamillosum
Rivularia biasolettiana
Oedogonium sp. 3
Zygnema b
Cyclotella comta
C. kützingiana v. *planetophora*
Anomoeoneis brachysira
A. brachysira v. *lanceolata*
Cymbella delicatula
C. microcephala
Epithemia argus
Stauroneis phoenicenteron
Tabellaria fenestrata
T. flocculosa

3.2.2 The ecological characteristics of the indicator algae

Descriptions of algal taxa representing species included in the six algal communities found with the Kolmogorov statistics (Chap. 3.2.1) are given below. Characterizations of all the taxa of this investigation are found in Johansson (1982). All the algae are taken in order according to Bourrelly (1966, 1968, 1970). The pennate diatoms are given in alphabetic order. The total dataset includes both very frequent taxa almost following the reference curves, such as *Rivularia biasolettiana*, and others that are less frequent which deviate in one or more cases (environmental parameters) from the reference curves such as *Eunotia lunaris*. Yet another type includes algae which are frequent at about 50 stations and which deviate in some parameters but not in others such as *Ceratoneis arcus* v. *linearis*. These are among the best indicators and will also be treated in Chapt. 6.5.

The taxa are treated first with a *reference* part in order to inform on the taxonomic literature used, as nomenclature is confused in several algological works. Synonyms are mentioned in cases where new names have been incorporated in algology but older names have been used in this study for practical reasons. The author characters for diatoms follow van Landingham (1967–1977) and those for bluegreens follow Starmach (1966). Other author characters are according to the reference literature used, marked with *.

In the *habitat* part each species is related to the reference curves representing the whole dataset for the 10 parameters (Fig. 13) while surrounding vegetation and bottom substrate are treated as percentage distribution (p.d.) both for the species itself and for the whole dataset. The p.d. for the whole of Jämtland as regards bottom substrate was as follows: cliff 4 %, boulders–stones 70 %, stones–gravel 10 %, gravel–sand 1 %, silt 8 %, organic material 1 % and higher plants (mosses included) 6 %. The surrounding vegetational types were distributed as follows: glacier areas 1 %, alpine heath 11 %, alpine birch forest 5 %, spruce forest 26 %, pine forest 4 %, mixed coniferous forest 4 %, deciduous forest 4 %, mixed deciduous and coniferous forest 18 %, clear-cut area 6 %, clear-cut area on one side of the stream and coniferous forest on the other 3 %, mire 6 %, pasture land 4 %, arable land 2 % and built up land 6 %. The percentage distribution and reference curves for the whole dataset are based on 501 stations.

The *literature* part is included for comparisons of habitat with other relevant investigations (subjectively chosen and of course not complete). These are chosen partly from areas with similar ecological conditions, e.g. mostly oligotrophic waters, and partly from papers treating the subject more generally with studies on ecological preferences of algal species.

CHLOROPHYTA
Oedogonium spp.

Ref.: Hirn 1900 (pp. 1–394); Skuja 1964 (p. 159, Pl. 25: 7–15, 26: 1–3); Bourrelly 1966 (p. 342, Pl. 70= 1–9)

Habitat: In Jämtland the *Oedogonium* species, treated together, occurred very frequently (in 103 of the 500 streams) and locally abundantly or even in masses, but they also grew as short single threads very close to the stones. Most Oedogonians were found sterile. They were divided into four groups, referring to the width of the cells: *Oedogonium* sp. 1. (4–14 μm). *Oedogonium* sp. 2 (15–22 μm). *Oedogonium* sp. 3 (23–32 μm), and *Oedogonium* sp.

4 (over 35 μm). *Oedogonium* sp. 2 was found at 45 localities, *Oedogonium* sp. 1 at 30, *Oedogonium* sp. 3 at 23, and the broadest, *Oedogonium* sp. 4, at 5 localities. There do not appear to be any ecological differences between *Oedogonium* sp. 1 and sp. 2 (Fig. 19). The curves for all parameters almost follow the ref. curve. *Oedogonium* sp. 3 deviates from the ref. curve because it was not found higher than at 600 m and as it seems to prefer larger streams. There are no records in streams below 8°C. Conductivity and calcium were lower than the ref. curve (Fig. 20).

All four groups were found in almost all types of habitats, although none was recorded from glacier areas.

Literature: A genus with worldwide distribution. Only a few references will be cited. – (*Nordic countries*) Skuja (1964), 24 different species in the Abisko area. Klasvik (1974), in Scania and in the Messaure area just north of the Arctic Circle. Kronborg (1975), very common in the Hjälmaren area where forms 24 μm and 41 μm broad only occurred in eutrophic waters. – (*Other countries*) Taylor (1928), from the Mts. of British Columbia, widely distributed but not abundant and quite rarely fertile. Messikommer (1942), frequent in lakes and small pools in the Davos Mts. Hirano (1969), five different *Oedogonium* species in the Nepal region of the Himalayas. Johansson (1976), four islands of the Azores and especially abundant in a stream at 600 m on S Jorge, with *Achnanthes minutissima* and *Gomphonema constrictum*.

Cladophora glomerata (L.) Kütz.

Ref.: van der Hoek 1963* (p. 162, Pl. 38); Bourrelly 1966 (p. 356, Pl. 75:7, 76:1–3)

According to van der Hoek (1963, p. 166): "Of all species of *Cladophora, C. glomerata* is probably the most variable one. The phases in the life history of plants growing in the same locality may show an extremely different morphology, and various environmental conditions may produce ecological modifications. The most characteristic form of *Cladophora glomerata*, which is, incidentally, also represented by its type specimen, is the one which grows attached to hard substrates in non-stagnant waters such as the wash of canals and lakes, streaming water of brooks and rivers, or the turbulent water of the Baltic shores."

Fig. 19–59. The cumulative distribution curves for 40 algal taxa as follows.

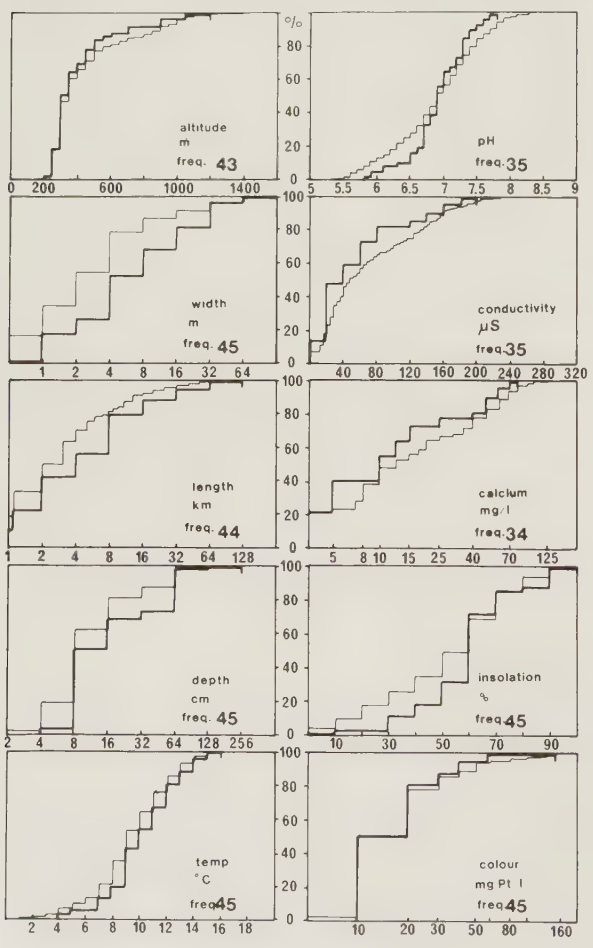


Fig. 19. *Oedogonium* sp. 2

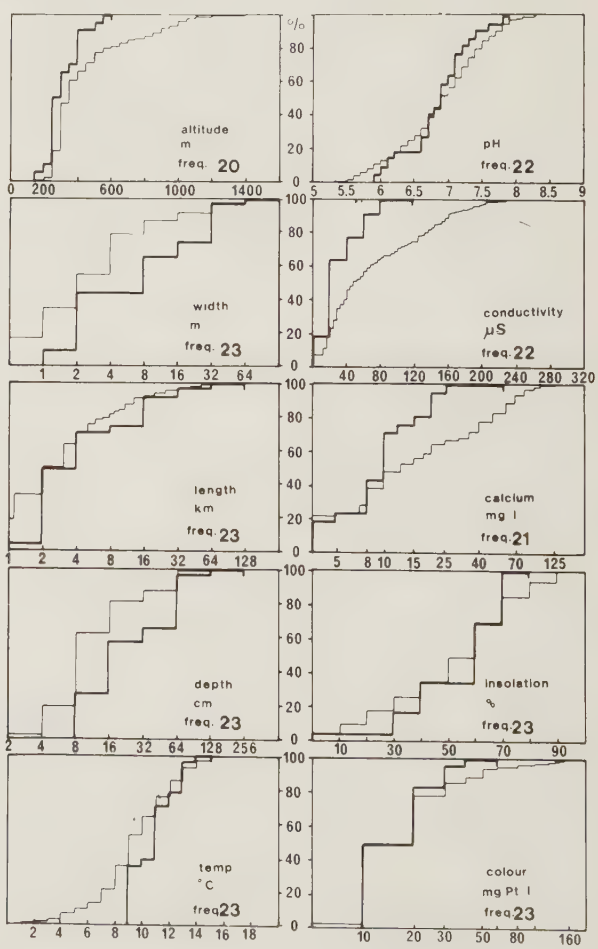


Fig. 20. *Oedogonium* sp. 3

Habitat: Recorded six times, not higher than 400 m, mostly in small rivulets with temperatures ranging between 6 and 11°C. pH between 7.5 and 8.3, conductivity between 80 and 180 μS, and Ca from 70 to 90 mg/l. The shading of the surrounding vegetation seems to influence the *Cladophora* plants negatively. The alga seems to prefer clear waters with colour values not above 30 mg Pt/l (Fig. 21). The records were from one stream flowing through deciduous forest, two through pasture land and three through arable land.

Literature: (*Nordic countries*) According to Israelson (1949) *C. glomerata* is the most conspicuous alga in a widely distributed type of *Vaucheria* streams and its green tufts, often united into luxuriant submerged meadows in early summer, are most easily recognized. Waern (1952) observed plants with large diameters in shady localities, which were exposed to wave action, and in eutrophicated water. Kronborg (1975) concludes that there are very few records from really oligotrophic areas. In his localities the conductivity ranges from 185–693 μS. – (*Other countries*) *C. glomerata* apparently needs a rather high light intensity for its development, the alga apparently needing eutrophic conditions, where the pH is rather high, 7.5 to 8.5 (van der Hoek 1963). Kann (1940, 1959), a luxuriant development in polluted waters. Also in calcium-rich waters (Kann 1978). Kolkwitz (1950) and Liebmann (1951), as oligosaprobic.

Zygnema group *b* (vegetative cells 21–29 μm in diameter, 1–3 diameters in length)

Habitat: Much more common than *Zygnema a*. In Jämtland in 87 localities, in 35 of these in masses. It was found in rather large streams with low conductivity and calcium content (Fig. 22) whereas pH nearly coincides with the ref. curve. The insolation estimation is also high since there is little shading effect of trees and shrubs in a broad river. The alga was found surrounded by all types of habitats, mostly by spruce forest, less frequently by pasture land and arable land.

Literature: According to Israelson (1949 p. 338) the distribution area is essentially the same as for *Zygnema a*, but *Zygnema b* seems to be remarkably uniformly distributed within the oligotrophic districts and is far more common. On the whole, specimens referred to this group are the most common in our non-calcareous streams.

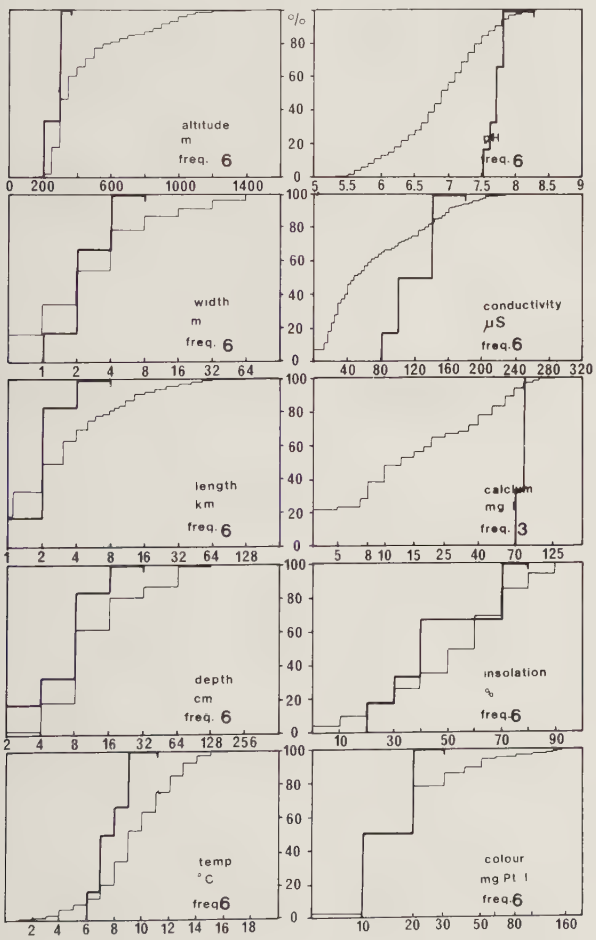


Fig. 21. *Cladophora glomerata*

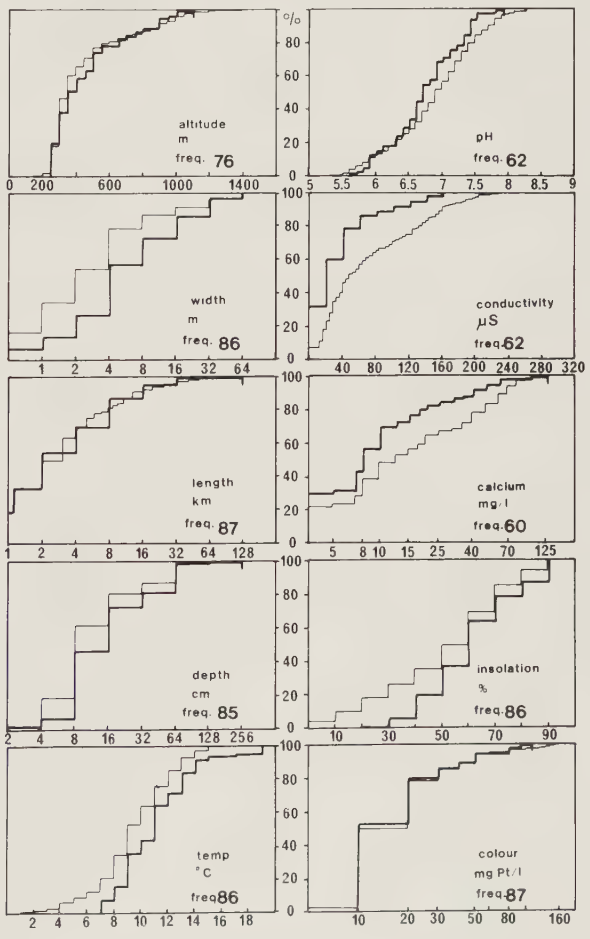


Fig. 22. *Zygnema b*

Mougeotia group *e* (vegetative cells 30–46(49) μm in diameter, 3–6 diameters in length)

Israelson (1949) stated that the characteristics of this group, as compared to *Mougeotia d*, are by no means distinct, making it probable that parts of the two groups are formed by the same species.

Habitat: Nearly as frequent (37 localities) as *Mougeotia d*. All parameters almost follow the ref. curve. (Fig. 23). In most types of habitats except in streams with a bottom substrate of gravel, silt or organic material. Not found in glacier areas, coniferous forests, or arable land.

Literature: Israelson (1949) stated that *Mougeotia e* is characteristic of waters poor in electrolytes all over Scandinavia, often being abundant. Sometimes it grows together with group *d* but in contrast to the latter it has never been found in eutrophic districts.

Spirogyra group *a* (vegetative cells 22–40 μm in diameter, 1.5–6 diameters in length)

Habitat: In 39 localities from the lowlands to the high mountains. In six localities it grew as cover degree 6 and in nine as 5. The distribution curves for the different parameters follow the ref. curve with a few exceptions; it was more frequently found in large streams, but conductivity and calcium content seemed to be lower (Fig. 24). The localities generally had a substrate of boulders, but occasionally stones, silt, organic matter or higher plants occurred. The surroundings consisted of montane vegetation (5 records), spruce forest (10), mixed forest (10), and populated land (8).

Literature: Israelson (1949) reported the group as distributed through the high mountain chain and in more or less closely adjacent regions; especially common and abundant in fairly or highly transparent waters poor in dissolved and suspended matter; brown humus-rich waters were avoided.

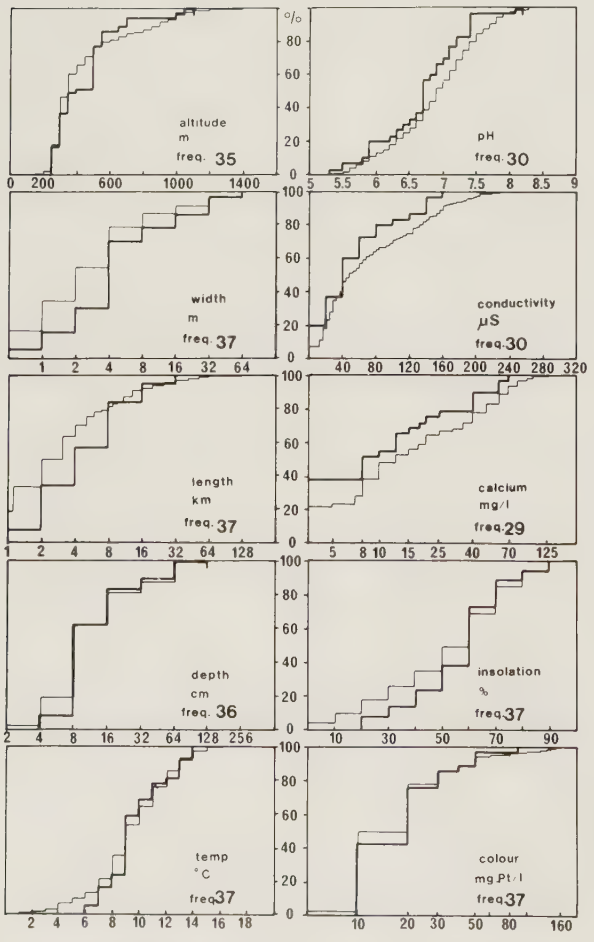


Fig. 23. *Mougeotia e*

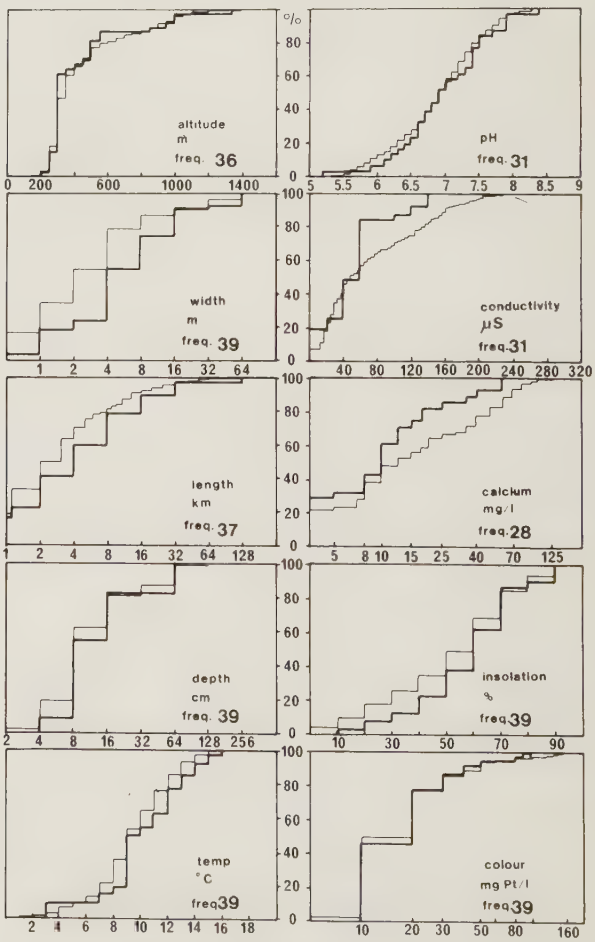


Fig. 24. *Spirogyra a*

Spirogyra group *c* (vegetative cells 32–58, usually 40 μm in diameter and 1–6 diameters in length, chloroplasts 3–5)

Habitat: Even more rare than *Spirogyra b*, as found in only nine streams. It preferred rather large streams at low altitudes, with low values of conductivity, not very shaded and with a colour content below 50 mg Pt/1 (Fig. 25). Surrounding vegetation mixed forest (4 stations), spruce forest (3), clear-cut area (1), mire and pasture land (1). The bottom substrate was boulders (6), stones (2) and silt (1).

Literature: Israelson (1949) *Spirogyra c* is widely distributed in Scandinavia and fairly common in southern Sweden but not frequent in the north.

Spirogyra group *d* (vegetative cells 60–88 μm in diameter, 1–3 diameters in length)

Habitat: In 13 streams. Recorded at altitudes between 200 and 700 m in rather small streams with high pH and low insolation values (Fig. 26). The group occurred only in streams with a bottom substrate of boulders. Various surrounding vegetation. Never in the mountains. Only once abundantly.

Literature: Israelson (1949), as not uncommon in very different regions and particularly in waters poor in dissolved matters, sometimes in abundance. High mountains were, however, avoided.

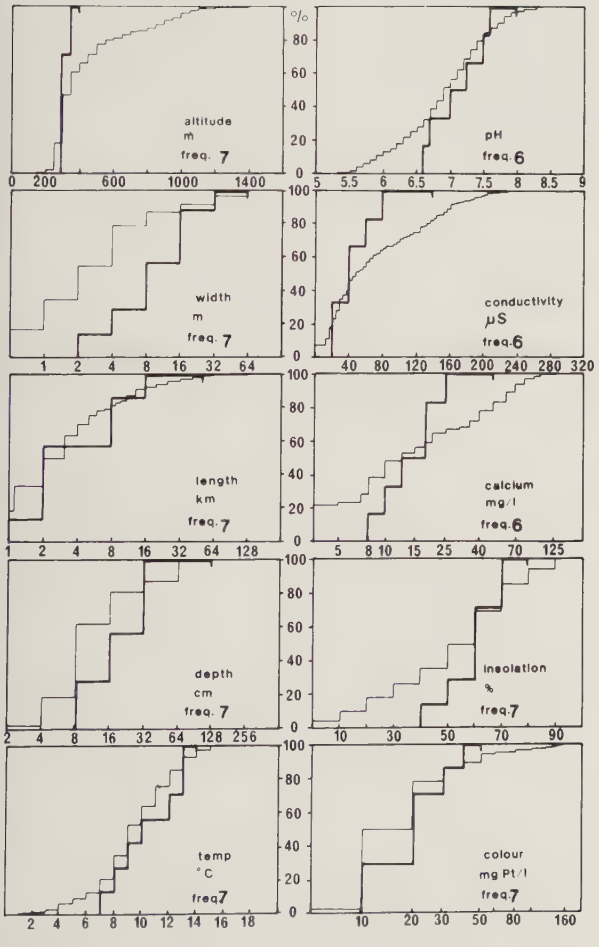


Fig. 25. *Spirogyra c*

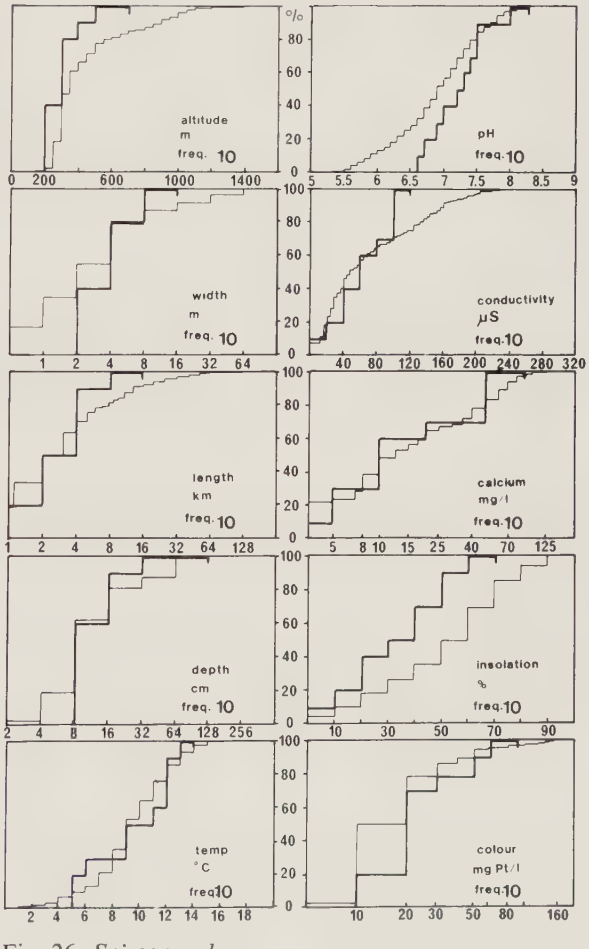


Fig. 26. *Spirogyra d*

CHROMOPHYTA
XANTOPHYCEAE
Vaucheria spp.

Ref.: Bourrelly 1968 (p. 230, pl. 47:3–4, 48, 49)

Habitat: *Vaucheria* spp. were found at 8 localities, always sterile. They preferred low altitude areas, small streams with low temperature, high pH (7.1 to 8.2), 140–320 μS and 35–150 mg Ca/l. The species grew in shaded habitats with low colour values of the water, 10–30 mg Pt/l (Fig. 27). In four cases the surrounding vegetation was mixed forest on limestone. Other records were in coniferous forest, decidious forest, clear-cut areas, and pasture land.

Literature: Israelson (1949) refers *Vaucheria* spp. to the so-called *Vaucheria*-streams in the southern parts of Sweden. Kronborg (1975) states that in well aerated waters *Vaucheria* species can withstand rather high pollution.

BACILLARIOPHYCEAE
Cyclotella comta (Ehr.) Kütz.

Ref.: Hustedt 1930 (p. 103, Fig. 69)

Habitat: The 13 records of *C. comta* are from altitudes between 200 and 600 m. It prefers broad streams, being mainly a planktic species. It also seems to follow the ref. curves for temperature and insolation. pH varies between 6.9 and 8.4, calcium content and conductivity seem to be lower than the ref. curve, but no record was made in waters with calcium content below 8 mg/l, nor in streams with colour above 50 mg Pt/l. Mostly in streams running through pine and spruce forests but also through populated areas (Fig. 28).

Literature: Hustedt (1930), as pelagic in stagnant and running waters, widely distributed and common.

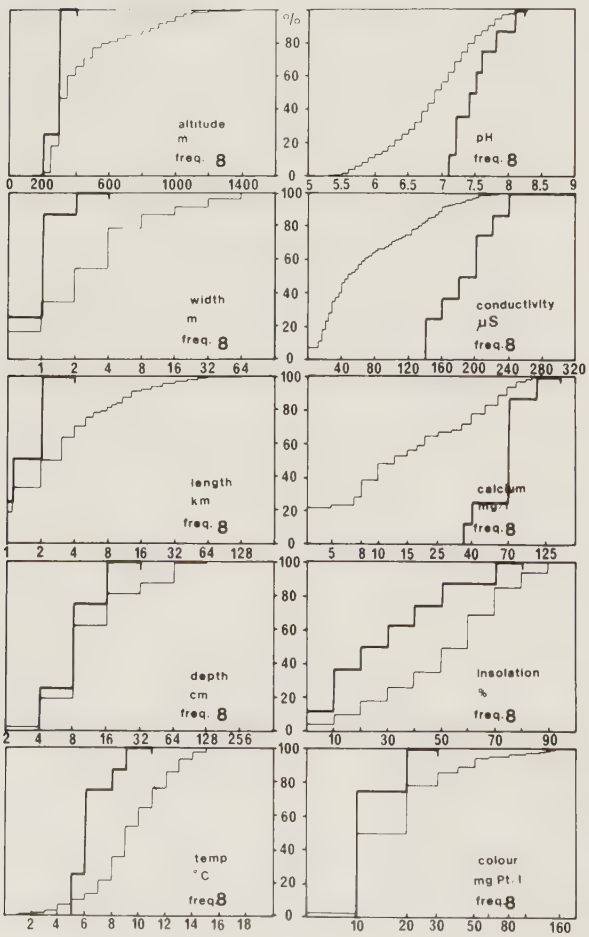


Fig. 27. *Vaucheria* spp.

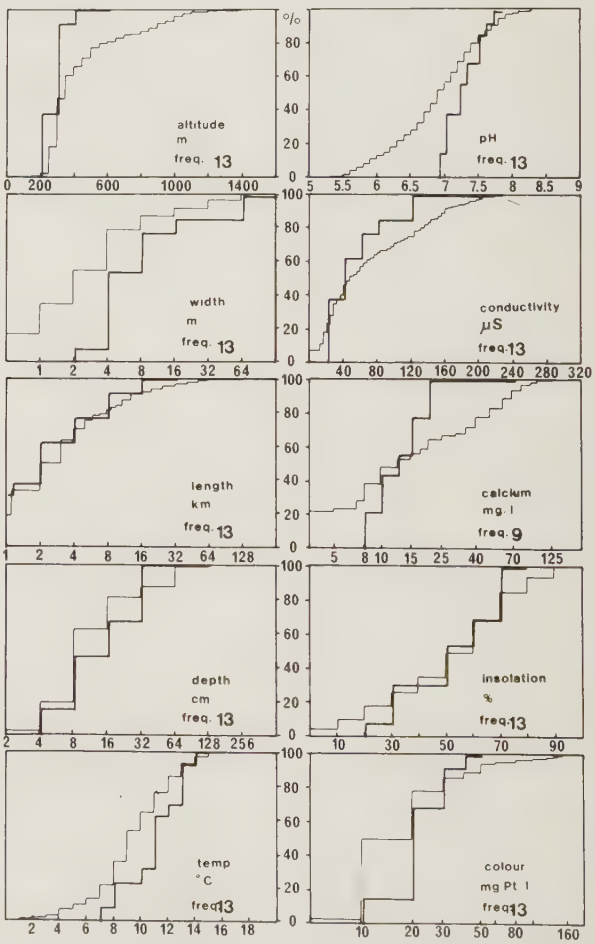


Fig. 28. *Cyclotella comta*

Cyclotella küzingiana Thwaites v. *küzingiana*

Ref.: Hustedt 1930 (p. 98, Fig. 62)

Habitat: Sparsely at 11 localities between 200 and 500 m, mostly in large rivers. The streams run through mixed forests and bog areas. pH 6.7–7.8, conductivity nearly followed the ref. curve, but calcium content was a little higher. Mostly found in not too shaded habitats, but the water colour was above 30 mg Pt/l (Fig. 29).

Literature: Cleve-Euler (1951), in lakes and streams, rarely in plankton. Most records from northern Scandinavia are from lakes. Skuja (1964), in scattered lakes in the Abisko area.

Cyclotella küzingiana v. *planteophora* Fricke

Ref.: Hustedt 1930 (p. 99, Fig. 63)

Habitat: In eight localities, very sparsely. Both calcium-rich and calcium-poor localities were recorded. (Fig. 30). Since the alga was not dominant or frequent anywhere, its main distribution may be more southern. Hustedt (1930) recorded the variety together with v. *kützingiana* in scattered lakes in northern Germany.

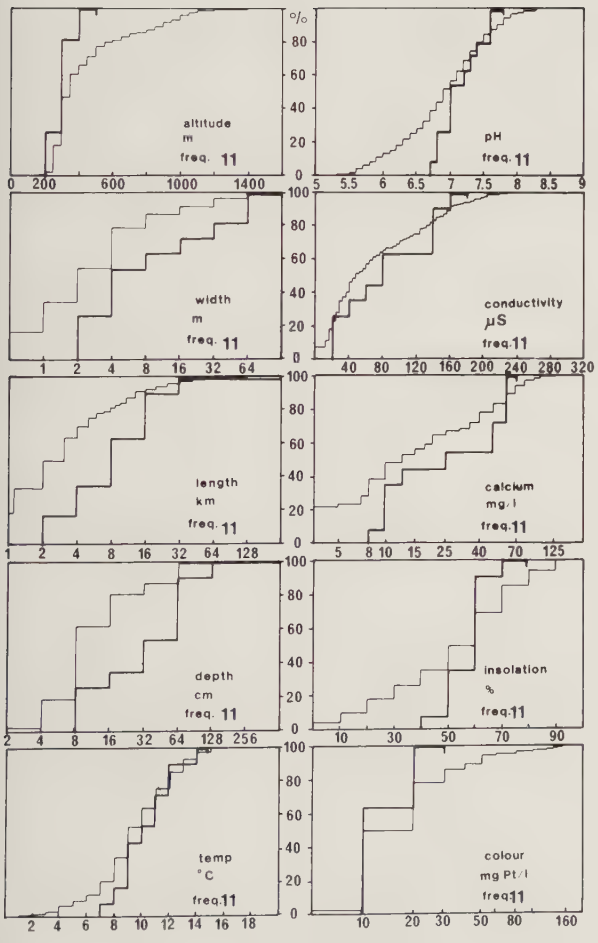


Fig. 29. *Cyclotella kützingiana*

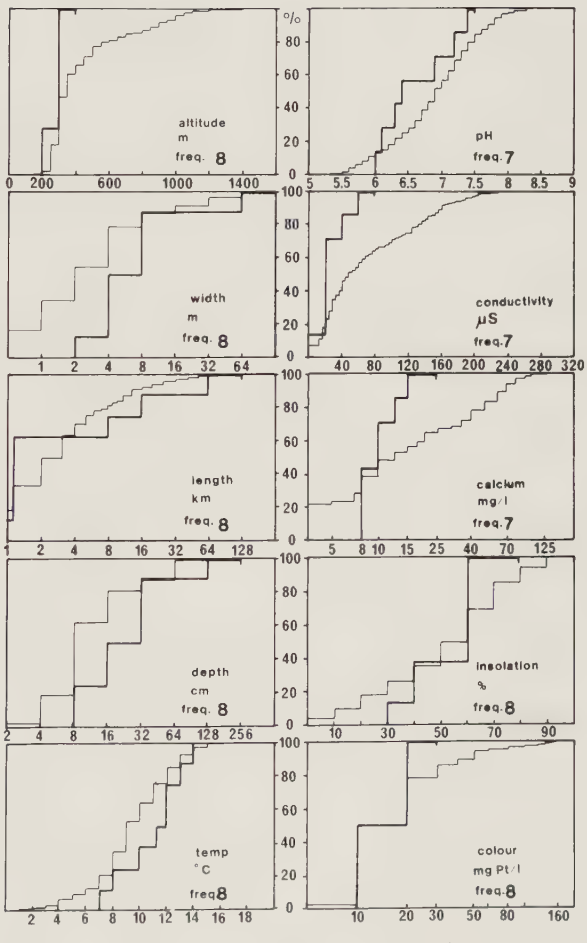


Fig. 30. *Cyclotella kützingiana* v. *planetophora*

Amphipleura pellucida Kütz.

Ref.: Hustedt 1931–59 (p. 724, Fig. 1095)

Habitat: *A. pellucida* is large and easily identified. Never frequently or abundantly. Size of the streams, temperature and colour follow the ref. curves but conductivity and calcium content seem to be higher and insolation lower. No records from areas above 800 m (Fig. 31). Frequently in streams running through spruce forests and with a substrate of higher plants.

Literature: (*Nordic countries*) Hustedt (1924), in only two samples from tarns in the Sarek Mts. Hustedt (1942), in Abiskojokk with pH 6.2–7.7, temperature 10.6–14.5°C; described as cosmopolitan, preferring alkaline waters. – (*Other countries*) Hustedt (1939), rare in the Pyrenees. Schroeder (1939), in the winter in the polluted River Mulde, Germany. Cholnoky (1968), alkaliphilous with pH optimum at 7.3. Sreenivasa & Duthie (1973), alkaliphilous, in a Canadian river. Love (1974), alkaliphilous, pH 6.2–8.0 (optimum 7.3).

Anomoeoneis brachysira (Bréb.) Grun.
Syn.: *A. serians* v. *brachysira* (Bréb.) Hust.

Ref.: Cleve-Euler 1953 b (p. 198, Fig. 919 a–b)

Habitat: In 42 samples (Fig. 32) preferring waters with low pH, conductivity, and calcium content at rather high altitude levels and with high insolation. Preferably surrounded by alpine heath and sub-alpine forests.

Literature: (*Nordic countries*) Hustedt (1924), common and widely distributed in the Sarek Mts. Hustedt (1942), preferring waters with pH under 7 in the Abisko area. Krasske (1943), in Lapland common in waters with a more or less acid character (4.4–6.9). Krasske (1949) in Lapland together with *Frustulia rhomboides* v. *saxonica* within the pH range 5.5–6.9. Quennerstedt (1955), one of the most common diatoms in the Långan river system in Jämtland. – (*Other countries*) Hustedt (1939), rare but abundant in a few localities in the Pyrenees. Cholnoky (1960), in Swartkops-stream in Cape Province, at rather low pH values. Cholnoky (1968), pH optimum at 5.2–

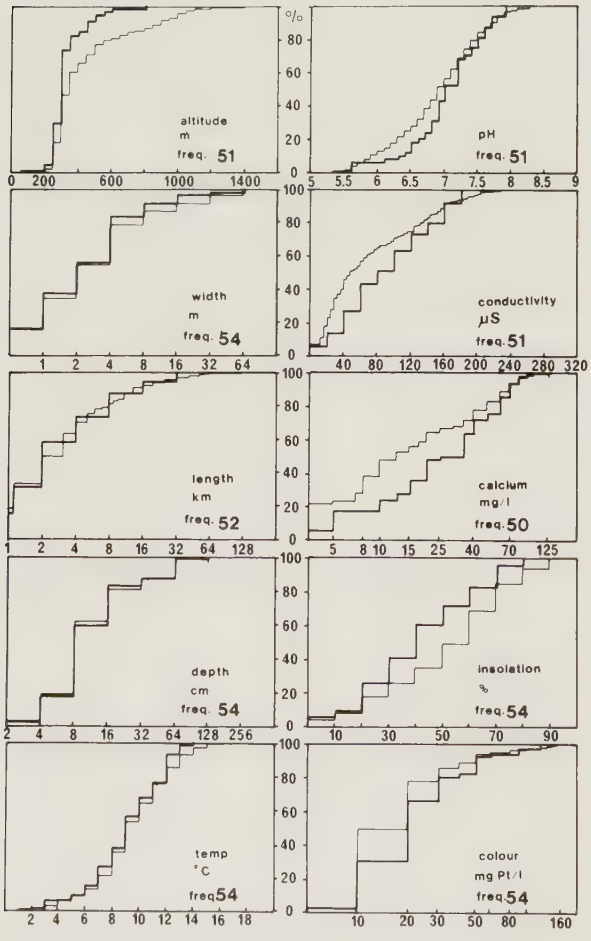


Fig. 31. *Amphipleura pellucida*

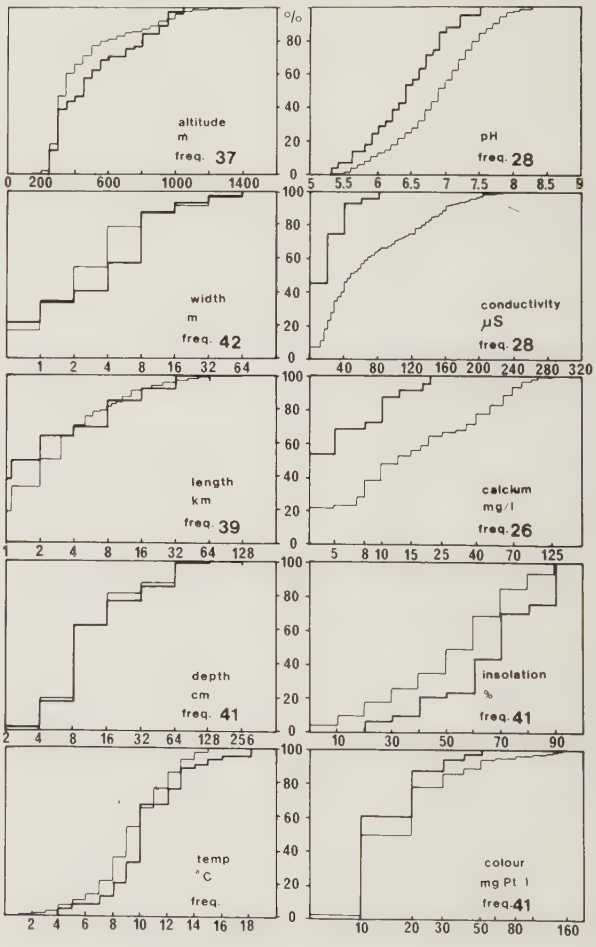


Fig. 32. *Anomoeoneis brachysira*

5.3, from samples in S African rivers. Lawson & Rushforth (1975) a few finds in the Provo River, Utah. Fabri (1977), from a station in La Warche with pH 6.9 and conductivity 94.5 µS, Ardennes. Fabri & Leclercq (1979), in streams with pH 5.2 and alkalinity 1.4 ppm $CaCO_3$ in the Hautes Fagnes area, Belgium.

Anomoeoneis brachysira v. *lanceolata* (A. Mayer) Cleve
Syn.: *A. exilis* v. *lanceolata* Mayer

Ref.: Cleve–Euler 1953 b (p. 199, Figs. 919 e–f)

Habitat: The distribution curves for the different parameters are almost the same as for the foregoing alga but the altitude is somewhat lower (Fig. 33). In streams located in spruce forests, mixed forests, clear-cut areas and populated land.

Literature: (*Nordic countries*) Cleve-Euler (1953b) recorded it only in Torne Lappmark. Quennerstedt (1955), very common in the Långan river system, Jämtland. — (*Other countries*) Fabri & Leclercq (1979), in a tributary to the Roer in Belgium.

Anomoeoneis brachysira v. *thermalis* (Grun.) Cleve
Syn.: *A. exilis* v. *thermalis* (Grun.) Cleve; *A. serians* v. *brachysira* f. *thermalis* (Grun.) Hust.

Ref.: Cleve-Euler 1953b (p. 198, Fig. 919 c, d)

Habitat: In all types of stream habitats in Jämtland, with a small preference for streams located in alpine heath with high insolation, temperature and depth (Fig. 34) with higher plants as dominating substrate.

Literature: (*Nordic countries*) Krasske (1949), from Lapland area. Cleve-Euler (1953b), in montane waters in Finnish and Swedish Lapland. Quennerstedt (1955), common in the Långan river system. — (*Other countries*) Messikommer (1942), near Davos at 1750 m and 2245 m. Hirano (1969), in a stream at 2800 m in Rangtang Himal., Nepal. Leclercq (1977), in Honsbach in the upper Ardennes (pH 6.9 and conductivity 71 µS).

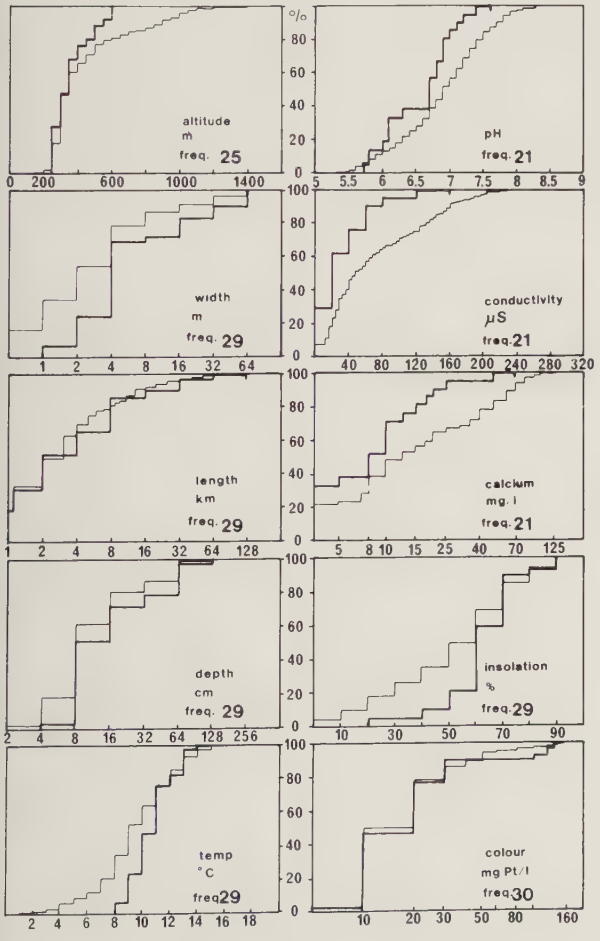


Fig. 33. *Anomoeoneis brachysira* v. *lanceolata*

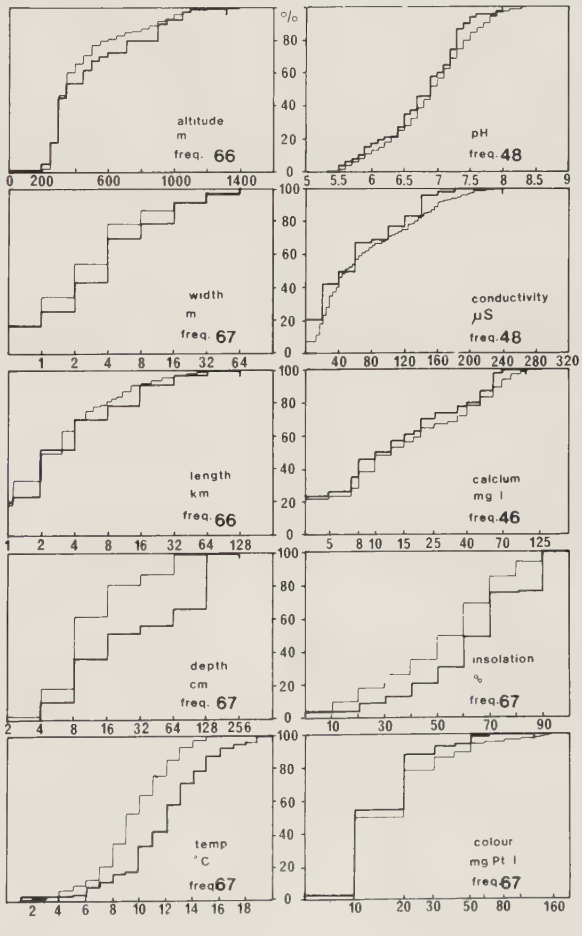


Fig. 34. *Anomoeoneis brachysira* v. *thermalis*

Ceratoneis arcus v. *linearis* Holmboe
Syn.: *Hannaea arcus* (Ehr.) Patr. v. *linearis* (Holmb.) Johans.

Ref.: Hustedt 1931–1959 (p. 180, Fig. 686 c)

Habitat: More frequent than the typical var., abundantly in 20 % of the streams. The ecology seems to follow the ref. curve but values for pH, conductivity and calcium content are lower (Fig. 35). In streams located to 16 % in alpine heath areas, 7 % in alpine birch forests and 33 % in spruce forests.

Literature: Many of the references are the same as for the typical variety so only a few will be added here (Johansson 1982). – (*Nordic countries*) Krasske (1949), especially in cold waters, in Finnish and Swedish Lapland. Quennerstedt (1965), in the spring flood in the large rivers of Sweden. Johansson (1980), all stones were covered by the var. *linearis* together with *Hydrurus foetidus*, in the Narssaq river, S Greenland.

Cocconeis placentula v. *euglypta* (Ehr.) Cleve

Ref.: Cleve-Euler 1953b (p. 8, Fig. 492 e–f)

Habitat: Much more frequent (66 localities) than the main var. and mostly found in streams below 650 m, with high values for pH, conductivity, and calcium (Fig. 36). No records from glacier areas or alpine streams, but three finds from the subalpine birch region.

Literature: (*Nordic countries*) Foged (1968), in 59 of the 203 samples from the Varanger peninsula, Norway. Foged (1980), as alkaliphilous on the limestone island of Öland. Warncke (1980), in 27 of the 196 springs on Jutland, Denmark. – (*Other countries*) Wehrle (1942), in the River Rhine, thus resistant to pollution. Hustedt (1957), as alkaliphilous and oligotrophic. Wasylik (1965), in the Sola River, 12.7–22°, pH 7.1–7.7, calcium 12.1–42.1 mg/l. Patrick & Reimer (1966), frequently in circumneutral to alkaline waters.

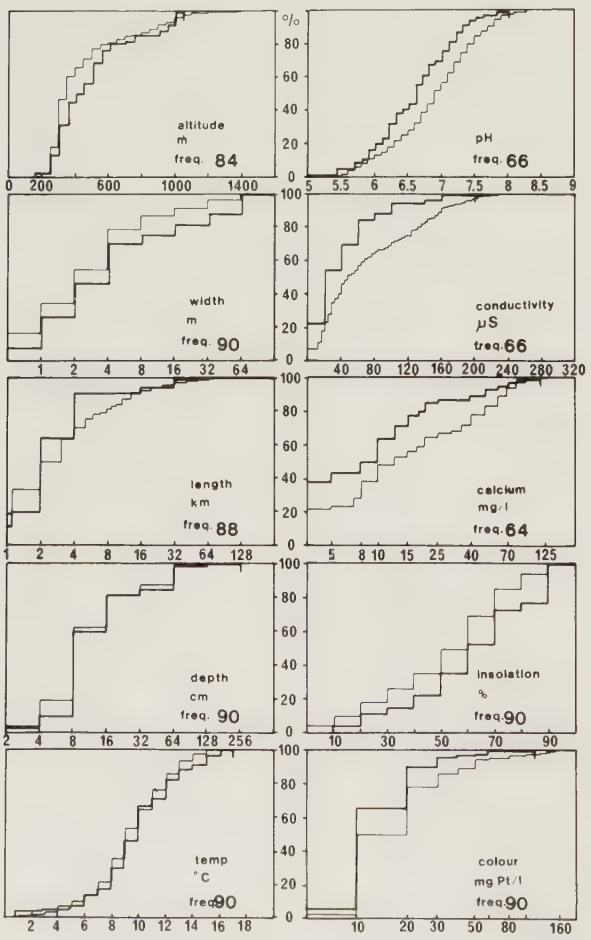


Fig. 35. *Ceratoneis arcus* v. *linearis*

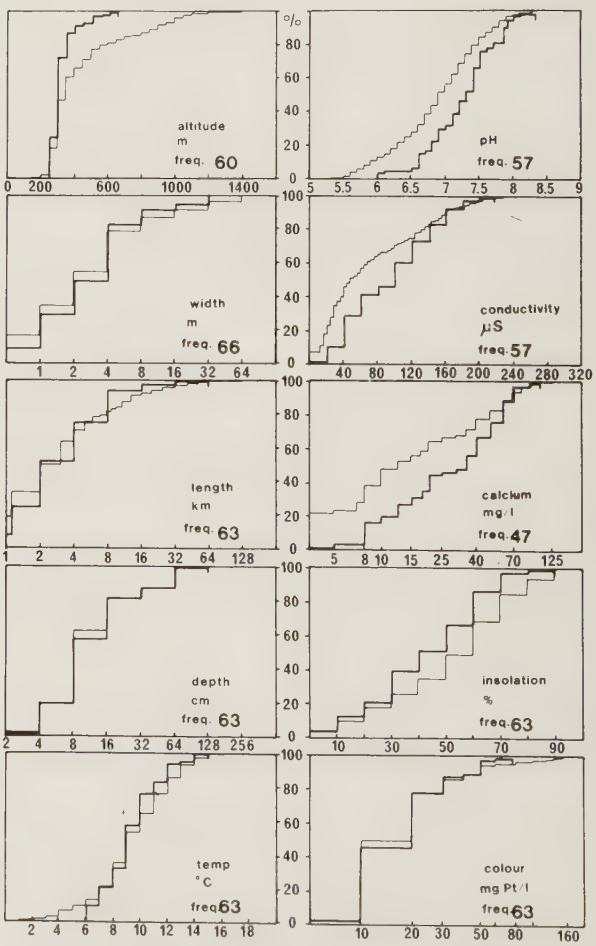


Fig. 36. *Cocconeis placentula* v. *euglypta*

Cymbella delicatula Kütz.

Ref.: Hustedt 1930 (p. 352, Fig. 642)

Habitat: Growing sparsely in streams from the lowland to the mountains with temperature 8–16°, pH 6.0–8.2 (mostly higher than 6.9), conductivity mostly in two different ranges, viz. 20–40 and 140–180 μS, calcium and insolation followed the ref. curve. Colour not above 40 mg Pt/l (Fig. 37). Many records are from streams in the alpine heath and sub-alpine birch forest.

Literature: (*Nordic countries*) Hustedt (1930) and Cleve-Euler (1955), on cliffs kept wet from spray in the mountains but otherwise scattered. Hustedt (1942), in Abiskojokk frequent, in other waters with pH 6.2–9.0, temperature 10.6–12°. Patrick & Reimer (1975), rarely in large numbers; listed occasionally from aerophilic habitats, most frequently reported from circumneutral to slightly alkaline waters.

Cymbella lunata W. Smith
Syn.: *Cymbella gracilis* (Rabh.) Cleve

Ref.: Patrick & Reimer 1975 (p. 46, Pl. 7:11–14)

Habitat: 10 records, 5 at high altitudes (1 in a glacier area, 4 surrounded by alpine heath). Mostly in small streams slightly more rapid than average, low temperatures, very low values for pH, conductivity, calcium and colour (Fig. 38).

Literature: (*Nordic countries*) Hustedt (1930), most frequent in the mountains, more seldom in the lowland. Quennerstedt (1955), very common in the oligotrophic lakes of the Långan river system. – (*Other countries*) Patrick & Reimer (1975), probably widely distributed in the US.

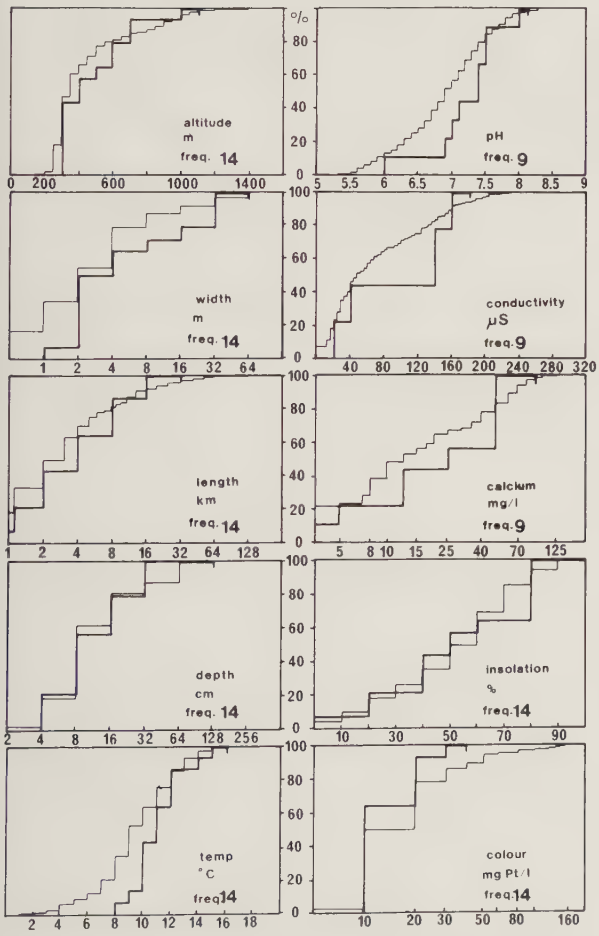


Fig. 37. *Cymbella delicatula*

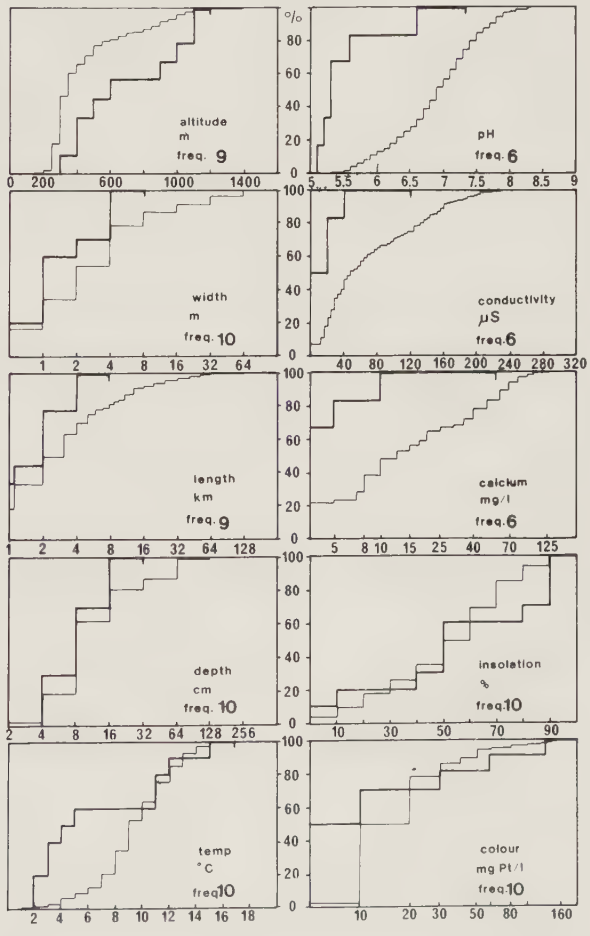


Fig. 38. *Cymbella lunata*

Cymbella microcephala Grun.

Ref.: Patrick & Reimer 1975 (p. 33, pl. 4:12a–13b)

Habitat: One of the most frequent algae in Jämtland; in 101 streams. The distribution curves for the different parameters agree with the ref. curve except for insolation, temperature and to some extent pH which are higher (Fig. 39).

Literature: A widespread alga found in many parts of the world; only a few works will be cited here. (*Nordic countries*) Hustedt (1924), in the Sarek Mts. Hustedt (1942), in the Abisko area in northern Sweden, in areas with pH 6.5–9 and temperature 9.5–15°C. Krasske (1949), in 28 samples in Lapland with pH range 6.5–6.9. Quennerstedt (1955), in the oligotrophic lakes of the Långan river system, Jämtland. – (*Other countries*) Hustedt (1939), in the Pyrenees. Messikommer (1942), frequent at 2455 m and at 1507 m in the Davos Mts. Cholnoky (1968), pH optimum 7.0–7.2, a good indicator of weakly alkaline and oligotrophic waters. Sreenivasa & Duthie (1973), in a Canadian river, as alkaliphilous. Love (1974), as alkaliphilous with pH optimum around 7.2, β-mesosaprobic, and indifferent to current. The latter statement in agreement with this study (Table 1). Benson & Rushforth (1975), throughout but never in abundance in the Huntington Canyon, Utah.

Diatoma hiemale v. *mesodon* (Kütz.) Grun.

Ref.: Patrick & Reimer 1966 (p. 108, Pl. 2:8)

Habitat: In 27 watercourses generally small; all parameters follow the ref. curve except temperature which is lower (Fig. 40); more than 40 % were streams with conductivity below 40 μS. To a great extent in streams with a bottom substrate of cliffs and a surrounding vegetation of subalpine birch forest. It grew in masses in one locality, Vindalsbäcken (No. 442), a slow-flowing stream in the limestone area of central Jämtland, with conductivity 192 μS, pH 7, and calcium 100 mg/l.

Literature: Several records available, mostly from montane areas where it often occurs abundantly. Only a few will be referred to here. (*Nordic countries*) Hustedt (1924), very frequent in the Sarek Mts. and much more common than v. *hiemale*. Hustedt (1942), in Abiskojokk and other waters in the Abisko area with temperature 7–10.6° and pH 6.2–6.3, but the alga prefers alkalic waters. Krasske

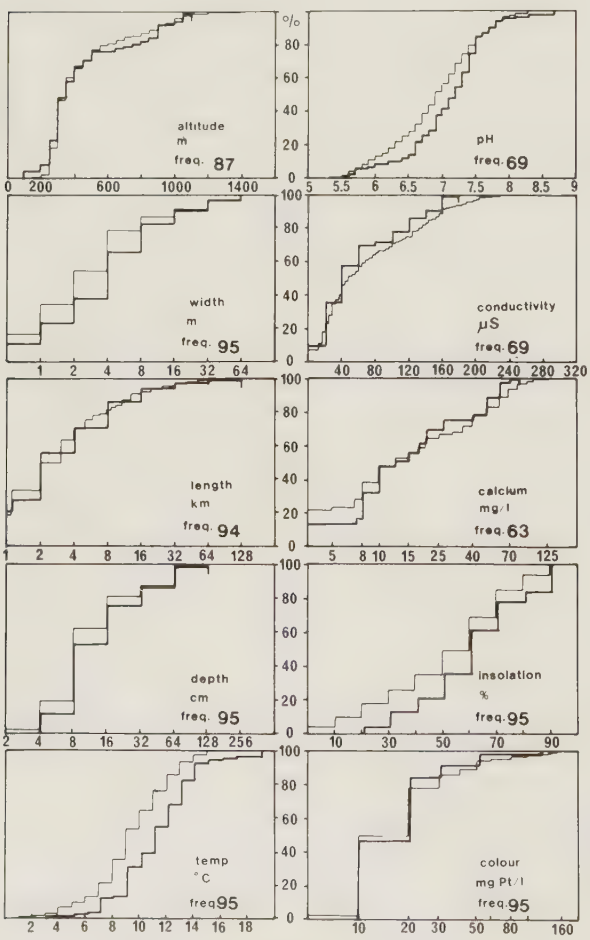


Fig. 39. *Cymbella microcephala*

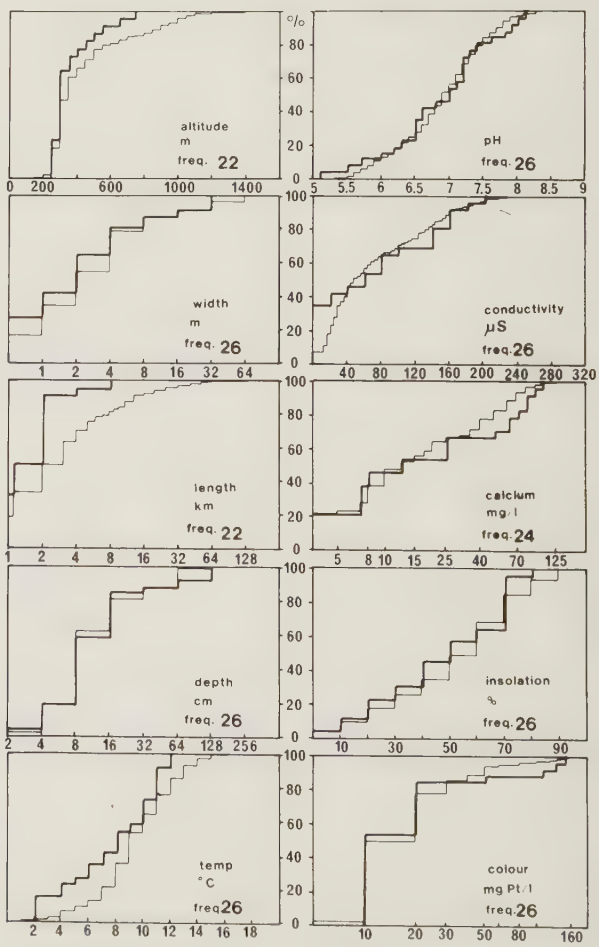


Fig. 40. *Diatoma hiemale* v. *mesodon*

(1943), as a coldwater form. Krasske (1949), in Swedish and Finnish Lapland with pH 6.3–6.5. – (*Other countries*) Kawecka et al. (1971), in the Polish High Tatras where temperature varied between 0.5–8.5°, pH 6.2–6.8, and calcium 2.5–3.7 mg Ca/l. Leclercq (1977), in the Hautes Ardennes (Belgium), favoured by low values of temperature, pH and mineralisation. Johansson (1980), in the Narssaq River in Greenland together with *Hydrurus foetidus*.

Diatoma hiemale v. *genuinum* Grun. f. *turgidula* (Kütz.) A. Cl.

Ref.: Cleve-Euler 1953a (p. 20, Fig. 328 a–c)

Habitat: From the 33 localities the alga seems to prefer altitudes below 450 m, pH above 6.6, relatively high values of conductivity, and calcium contents; waters with colour values below 60 mg Pt/l (Fig. 41). Proportionally large amounts of the diatom were found in streams with a dominance of higher plants as bottom substrate. Surrounding vegetation almost as p.d.

Literature: Cleve-Euler (1953a), mostly in running waters in northern parts of Scandinavia.

Epithemia argus (Ehr.) Kütz.

Ref.: Hustedt 1930 (p. 383, Fig. 727a)

Habitat: A preference (8 records) of large, low altitude streams with high temperature and rather high colour content (Fig. 42). Spruce and mixed forest surrounded the streams in 6 cases.

Literature: (*Nordic countries*) Hustedt (1924), occasional in Sarek. Hustedt (1942), near the Tourist hotel at Abisko. Krasske (1949), in Lapland in waters with pH 6.7–6.9. Quennerstedt (1955), in the oligotrophic lakes Landösjön and Yttre Oldsjön in Jämtland. Foged (1964), common in Spitsbergen. Foged (1968), frequent in the Varanger peninsula, Norway. – (*Other countries*) Messikommer (1942), common in the high mountains of Davos. Lawson & Rushforth (1975), not uncommon and occasionally occurring in large numbers in the Provo River, Utah.

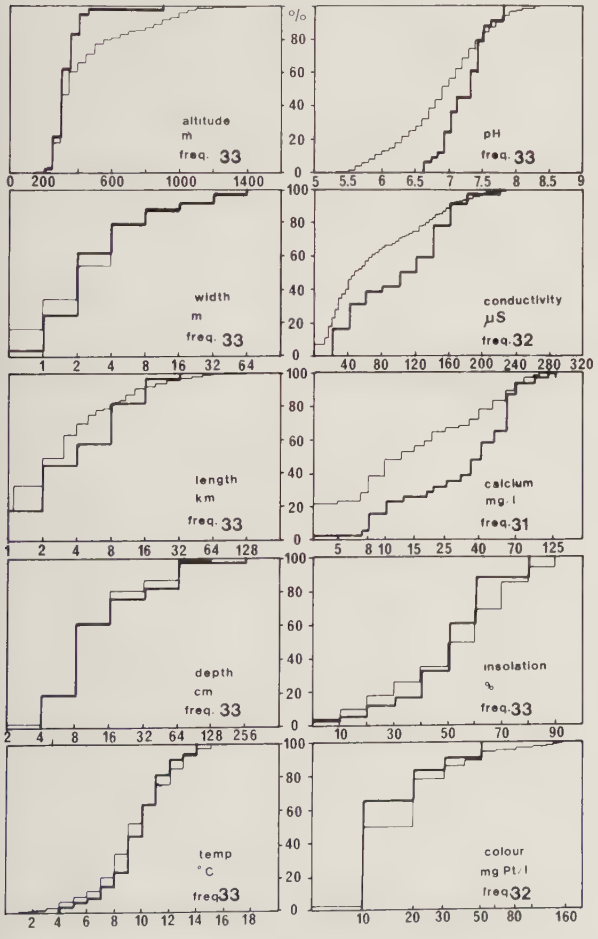


Fig. 41. *Diatoma hiemale* f. *turgidula*

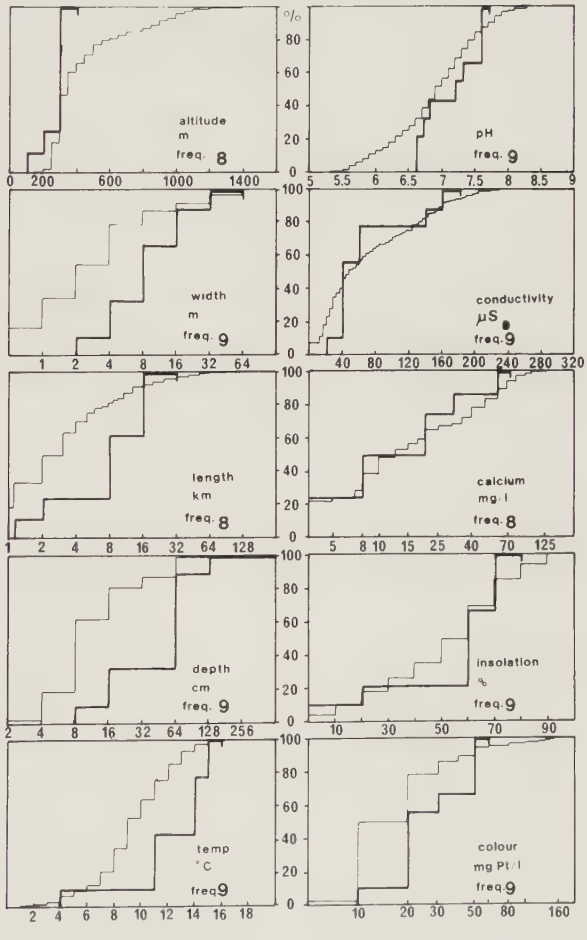


Fig. 42. *Epithemia argus*

Eunotia lunaris (Ehr.) Bréb.

Ref.: Hustedt 1931–59 (p. 302, Fig. 769 a, b, d, e)

Habitat: The species seems to prefer (13 localities) high altitude, high temperature, low values of pH, conductivity and calcium, and high insolation (Fig. 43). The surrounding vegetation was alpine heath to 54 % and spruce forest to 23 %.

Literature: (*Nordic countries*) Hustedt (1924), widely distributed in Sarek. Hustedt (1942), under various habitat conditions in the Abisko area, with pH 4.6–6.7 and 5.5–15.5°C. Krasske (1949), the most common diatom in the investigated area in Lapland. Foged (1968), very frequent in the Varanger peninsula mostly within the pH range 6.5–7.4. – (*Other countries*) Wehrle (1942), widely distributed in the Schwarzwald with a large ecological amplitude pH 6.3–7.4. Messikommer (1942), rare in the high mountains of Davos. Foged (1964), in Spitsbergen. Hirano (1969), in a small stream at 3800 m in Nepal. Foged (1973), in many localities in NW Greenland. Fabri & Leclercq (1979), in all streams studied in the Hautes Fagnes, Belgium.

Eunotia pectinalis (Dillw.; Kütz.) Rab. v. *pectinalis*

Ref.: Patrick & Reimer 1966 (p. 204, Pl. 12:8–10)

Habitat: Seems to prefer streams at rather high altitudes and rather low values of pH, conductivity and calcium, rather high insolation and rather low colour (Fig. 44). It occurred to 24 % in streams in alpine heath and alpine birch forest.

Literature: Several records from many parts of the world. Only a few papers will be referred to below. – (*Nordic countries*) Hustedt (1924), widely distributed in the Sarek mountain area. Hustedt (1942), sparse in the Abisko area. Eloranta & Kunnas (1979), one of the most common diatoms of the Tourijoki river system in Finland, with pH about 6.0, 40 µS, and colour 40–91 Pt/l. – (*Other countries*) Wehrle (1942), from the Schwarzwald, only in waters with a pH below 7.0, otherwise probably with a wide ecological amplitude. Hustedt (1957), described from the Weser as oligosaprobic, acidophilic, but also found in alkalic waters. Cholnoky (1960), in the Swartkops-stream in Kaapland with a pH of about 6.0. Hirano (1969), in the Himalayas at 3800 m in a small stream. Sreenivasa & Duthie (1973), pH indifferent, Grand River, Canada. Johansson (1976), in the Azores in most habitats on all of

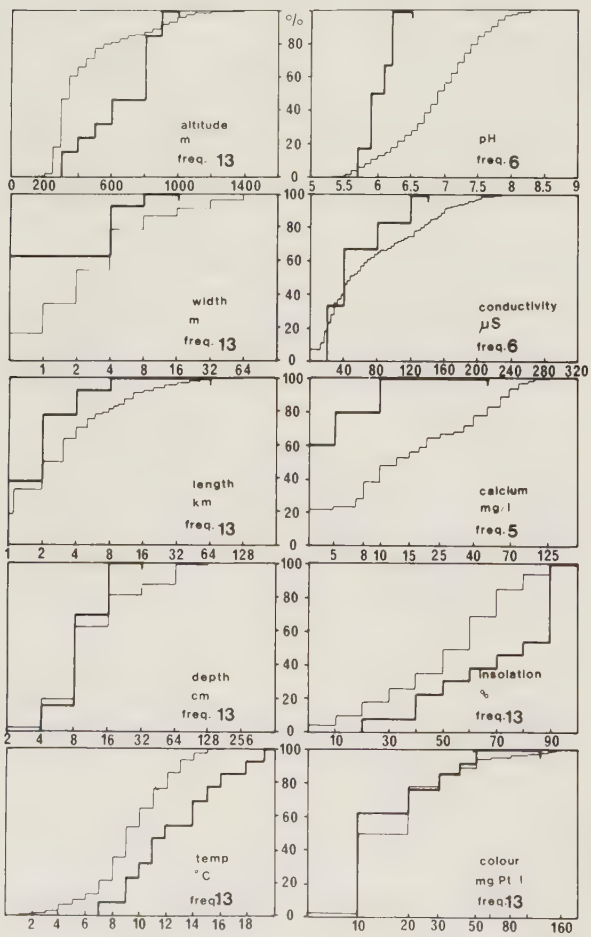


Fig. 43. *Eunotia lunaris*

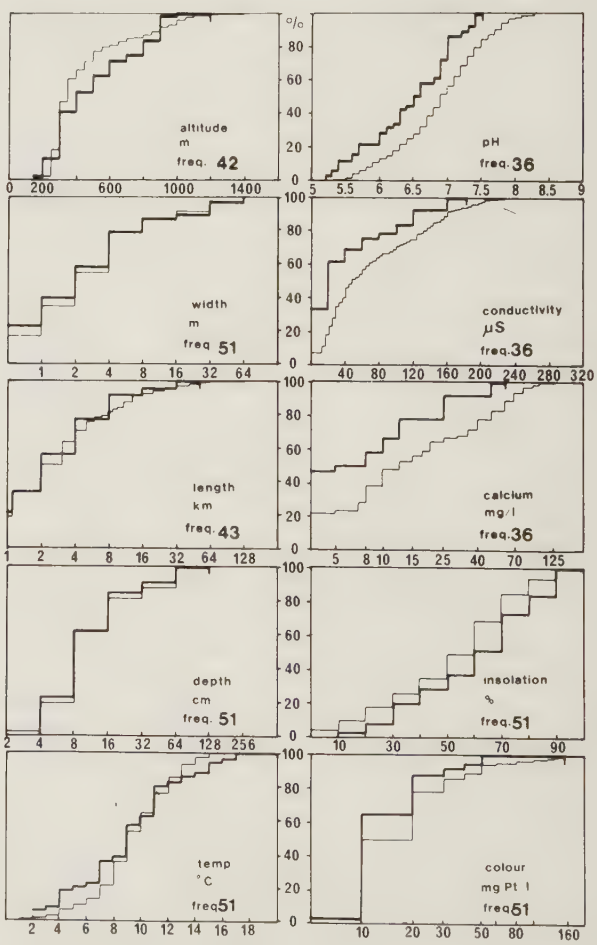


Fig. 44. *Eunotia pectinalis*

the islands visited. Fjerdingstad (1950), in the Mølleå as α-mesosaprobic. Sládeček (1973), as xenosaprobic. Love (1974), as acidophilous (range pH 5—8, optimum around 6.5), oligotrophic to eutrophic, oligosaprobic to α-mesosaprobic, indifferent to current velocity, cosmopolitan geographical distribution. Mauch (1976), as oligosaprobic to β-mesosaprobic.

Eunotia pectinalis v. *minor* (Kütz.) Rab.

Ref.: Hustedt 1931—59 (p. 298, Fig. 763 d—f)

Habitat: Widely distributed in Jämtland. Found in 83 streams. At rather high altitudes, in waters with low values of pH, conductivity, and calcium; rather high insolation (Fig. 45). The var. was mostly found in streams located in alpine heath and alpine birch forest.

Literature: (*Nordic countries*) Hustedt (1924), more frequent than v. *pectinalis* in Sarek. Krasske (1942), in several waters in Abisko with pH 4.6—6.7 and 5.5—10.8°C. Hustedt (1942), in the Abisko area in habitats with pH 4.6—6.7 and 5.5—10.8°C. Foged (1968), very common in the Varanger peninsula, mostly within the pH range 6.5—7.4. — (*Other countries*) Wehrle (1942), more common than v. *pectinalis* in the Schwarzwald. Hirano (1969), in a branch river of the Rangtang at 3800 m, in the Himalayas. Foged (1973), in some localities in SW Greenland. Johansson (1976), in the Azores with *Zygnema* sp. as a very dense algal vegetation in ravines. Lawson & Rushforth (1975), very common in the Provo River, Utah. Sládeček (1973), as oligo- to xenosaprobic. Mauch (1976), oligosaprobic to α- and β-mesosaprobic.

Fragilaria construens (Ehr.) Grun. v. *construens*

Ref.: Hustedt 1931—59 (p. 156, Fig. 669 f—k)

Habitat: In rather large streams with high temperature; pH follows the ref. curve, within the range 6.0—7.7; low values for conductivity and rather low for calcium (Fig. 46). A rather high percent of the bottom types was silt but the surrounding vegetation almost follows the p.d. although with many streams running through a bog.

Literature: (*Nordic countries*) Hustedt (1924), mass production in four of the small lakes in Sarek, otherwise dispersed. Hustedt (1942), in the Abisko area. Krasske (1949), in Lapland in localities with pH 6.8 or 6.9. Foged (1968), in the Varanger peninsula mostly within the pH range of 6.5—7.4. — (*Other countries*) Hustedt (1939), in the Pyrenees. Wehrle (1942), in montane streams in the

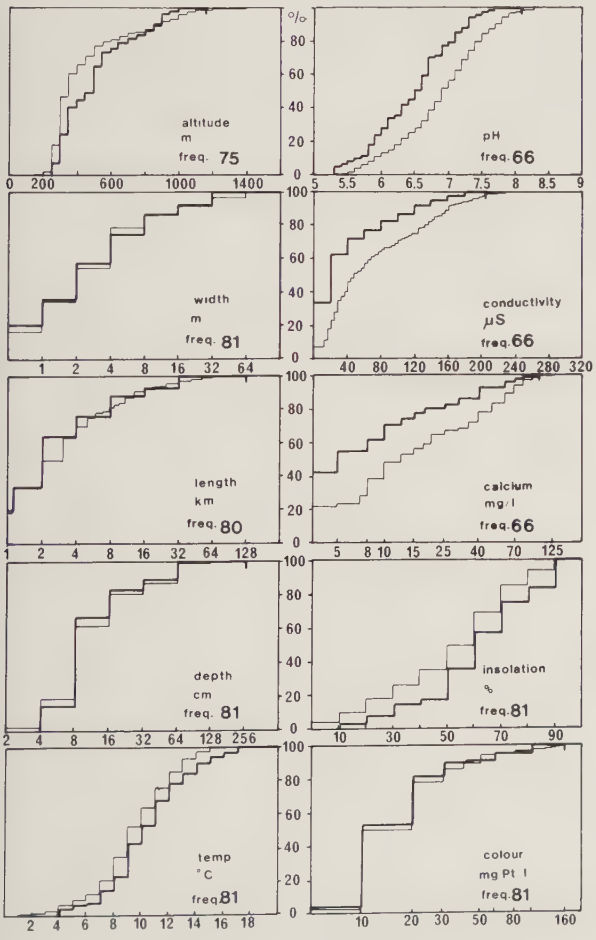


Fig. 45. *Eunotia pectinalis* v. *minor*

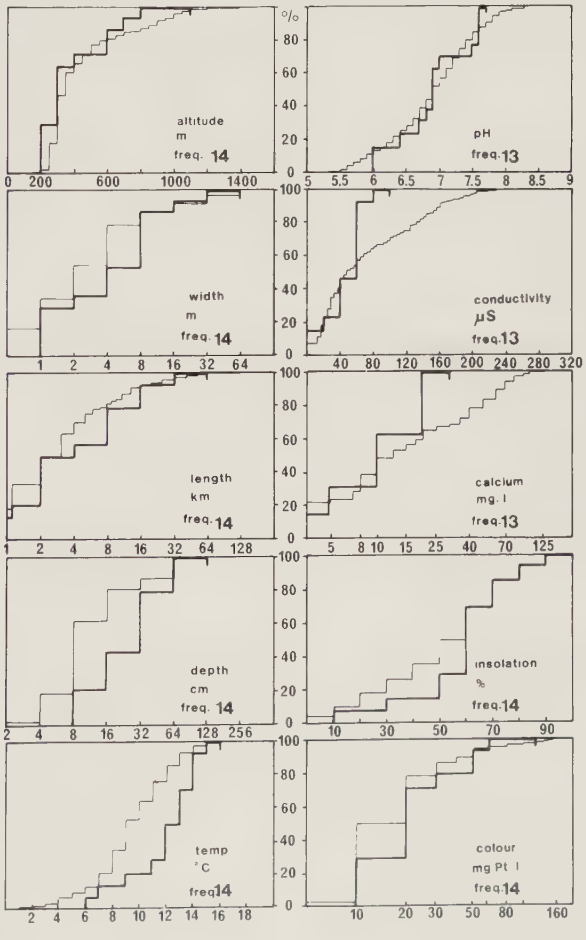


Fig. 46. *Fragilaria construens*

Schwarzwald, having a wide ecological amplitude, best developed in slightly acid waters. Foged (1973), in 13 samples in SW Greenland. Sreenivasa & Duthie (1973) in the Grand River, Canada, as alkaliphilous.

Frustulia rhomboides (Ehr.) De Tony v. *rhomboides*

Ref.: Patrick & Reimer 1966 (p. 306, Pl. 21:5)

Habitat: All parameters but colour deviate from the ref. curve (Fig. 47). The substrate in the streams was predominantly boulders and cliffs; there was more frequently a surrounding vegetation of alpine heath or alpine birch forest than expressed by the p.d.

Literature: (*Nordic countries*) Hustedt (1924), widely distributed in the Sarek Mts. Hustedt (1942), only in one pond in Abisko. Krasske (1949), in 22 samples in Lapland, pH 6.3–6.9. Quennerstedt (1955), very common in the very oligotrophic Lake Långan system. Foged (1968), in 44 localities in the Varanger peninsula mostly within the pH range 5.5–6.4. Håkansson (1980), in the estuary of the Kalix River, as saproxene. – (*Other countries*) Foged (1973), in many localities in SW Greenland. Lawson & Rushforth (1975), in the upper part of the Provo River, Utah, Fabri & Leclercq (1979), in six streams in the Hautes Fagnes, Belgium. Johansson (1980), in the Narssaq area, SW Greenland.

Frustulia rhomboides v. *capitata* (A. Mayer) Patr.
Syn.: *Frustulia rhomboides* v. *saxonica* f. *capitata* (A. Mayer) Hust.

Ref.: Patrick & Reimer 1966 (p. 307, Pl. 21:8)

The difference from the v. *saxonica* is not distinct but frustules with well-marked capitate shape are here referred to as v. *capitata*.

Habitat: The streams in which the taxon were found seem to be located at high altitudes, with low values of pH, conductivity, and calcium while insolation was high (Fig. 48). 36 % of the streams were located in alpine heath, while affected areas seemed to be avoided.

Literature: Johansson (1976), in a rich algal flora on *Sphagnum* tufts on crater walls in the Azores. Cholnoky (1960), as preferring low pH values.

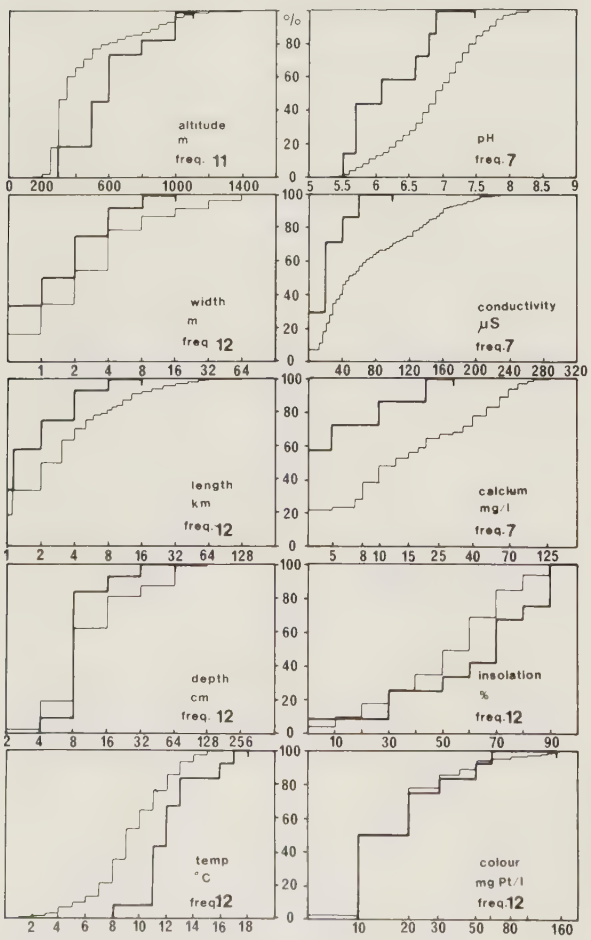


Fig. 47. *Frustulia rhomboides*

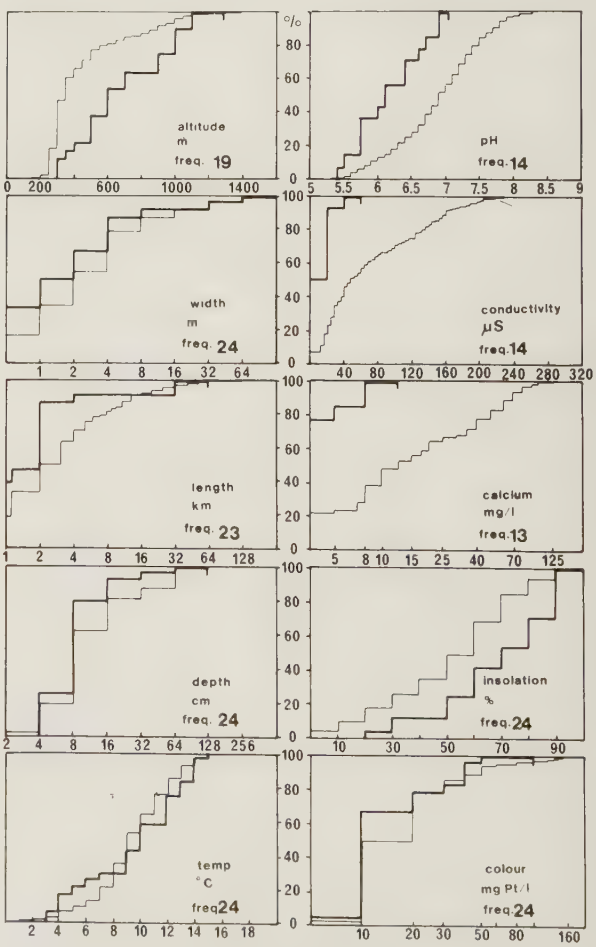


Fig. 48. *Frustulia rhomboides* v. *capitata*

Frustulia rhomboides v. *saxonica* (Rab.) De Tony

Ref.: Patrick & Reimer 1966 (p. 308, Pl. 21:7)

Habitat: In streams of mean velocities, at rather high altitude, low pH, conductivity, calcium, and high insolation (Fig. 49). Surrounding vegetation is more frequently alpine heath and alpine birch forest while other habitats are less frequent than expressed by p.d. for whole of Jämtland.

Literature: (*Nordic countries*) Foged (1964), in Spitsbergen in localities with pH values down to 5.0. Hustedt (1942), as an indicator of acid waters; found within the Abisko area, the pH range of 6.2—6.8 and 10.6—15.5°. Quennerstedt (1955), very common in the Lake Långan system of Jämtland. Håkansson (1980), in the Kalix River as acidophilous. — (*Other countries*) Foged (1964), in Spitsbergen with pH below 5.0. Cholnoky (1968), at pH 6 or below 6, in S Africa. Hirano (1969), in a glacier-rill in the Nepal Mts. Foged (1973), very common in SW Greenland. Johansson (1976), common in the Azores. Leclercq (1977), as acidophilous in the Hautes Ardennes, Belgium.

Gomphonema intricatum Kütz. v. *intricatum*

Ref.: Patrich & Reimer 1975 (p. 135, Pl. 18:1)

Habitat: In 49 streams, never abundantly, almost following the ref. curve although altitude seems to be lower (Fig. 50). Surrounding vegetation and bottom substrate also follow the p.d.

Literature: (*Nordic countries*) Hustedt (1924), sparsely in Sarek. Krasske (1942), rare in Lapland due to the acid character of the waters. Foged (1968), in 51 of the 203 samples, mostly in waters with pH 6.5—7.4, on the Varanger peninsula. Foged (1980), from 13 of 38 localities on Öland, many of them in *Chara* biotopes, as alkaliphilous. Håkansson (1980), only a few percent of the total biomass of diatoms in the estuary of the Kalix River. Warncke (1980), in 59 of the 196 samples from different springs on Jutland, Denmark. — (*Other countries*) Messikommer (1942), very rare in the high mountains of Davos. Foged (1964), in only three of the 34 localities in Spitsbergen. Cholnoky (1968), pH optimum 7.2—7.3, in S Africa. Foged (1973), in six of the 30 localities in SW Greenland. Benson & Rushforth (1975), not common in the Huntington Canyon, Utah.

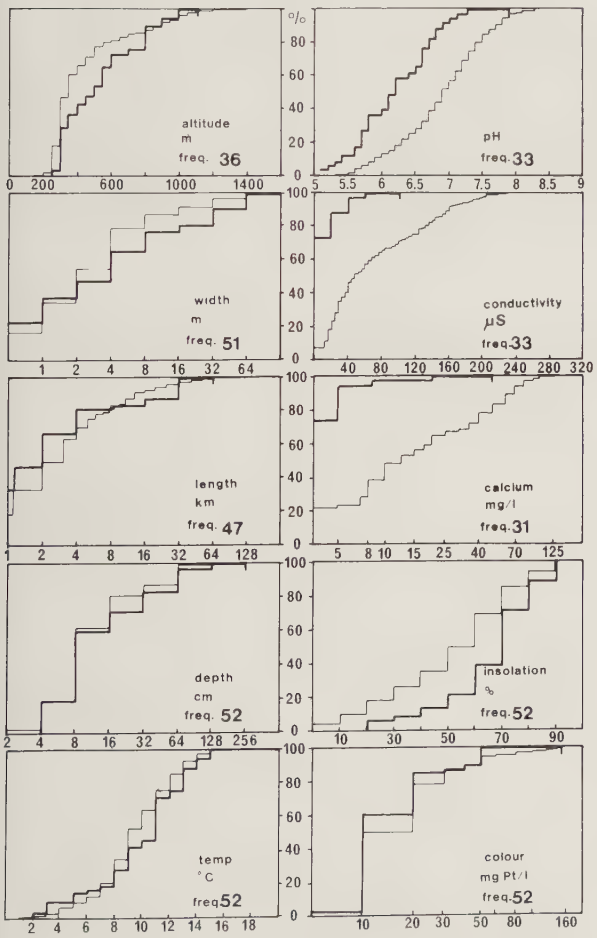


Fig. 49. *Frustulia rhomboides* v. *saxonica*

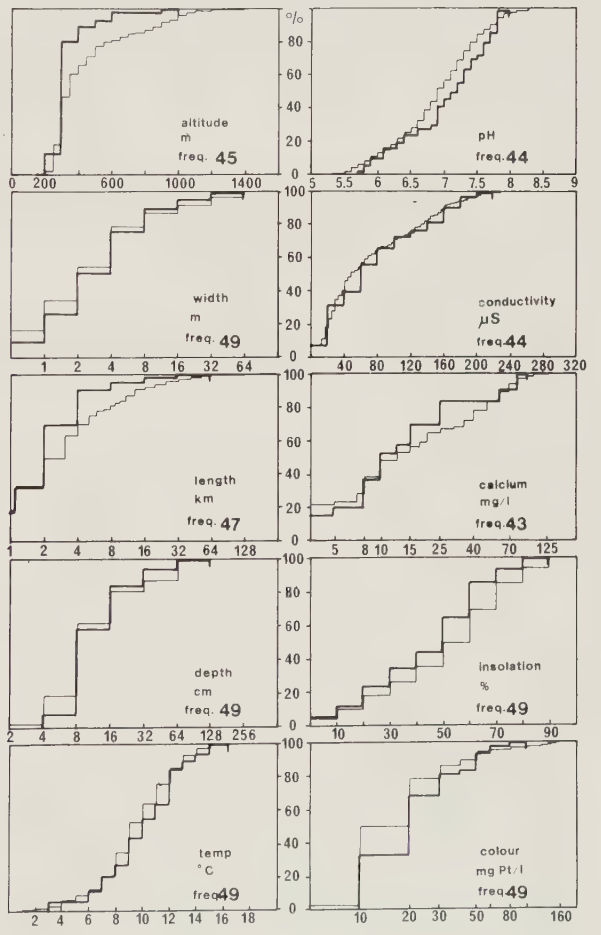


Fig. 50. *Gomphonema intricatum*

Gomphonema intricatum v. *pumila* Grun.

Ref.: Hustedt 1930 (p. 375, Fig. 699)

Habitat: The eleven localities were of average size, at altitudes below 600 m; temperature, pH, conductivity, calcium a little higher than the ref. curve, and colour not above 50 mg Pt/l (Fig. 51). Bottom substrate and surrounding vegetation differ rather much in some cases from the p.d., e.g. pine forest 23 %, conif. forest 15 % and no finds in montane areas.

Literature: (*Nordic countries*) Hustedt (1924), more frequent than the typical var. in Sarek. Hustedt (1942), only in one pond, with pH 7.7 and 14.5°C near the railway in Abisko. Krasske (1949), only in one locality in Lapland. Quennerstedt (1955), in Landösjön, a lake with pH 6.5–6.6 and conductivity 15.6–17.3 µS (July 1946 and 1947). Foged (1968), in eight of the 203 localities mostly within the pH range 6.5–7.4, on the Varanger peninsula. Foged (1980), in 12 of the 38 localities, on the island of Öland. Håkansson (1980), in very small amounts in the estuary of the Kalix River, N Sweden. Warncke (1980), in 25 of 196 localities in springs in Jutland, Denmark. – (*Other countries*) Hustedt (1939), on stones and mosses in the Pyrenees. Messikommer (1942), very rare in the high mountains of Davos. Sreenivasa & Duthie (1973), in one station, with pH around 8.5 and high conductivity around 350 µS, in the Grand River, Canada.

Meridion circulare (Grev.) Ag.

Ref.: Hustedt 1930 (p. 130, Fig. 118)

Habitat: Found in slow-flowing rather small streams with temperature and colour lower than the ref. curve; pH, conductivity, and calcium higher than the ref. curve (Fig. 52). Most streams flowing through lowlands in mixed forest, pasture land and coniferous forest.

Literature: (*Nordic countries*) Hustedt (1924), very common and locally abundant in Sarek. Hustedt (1942), very common and abundant, 3.6–10.8°C, pH 6–7, in the Abisko area. Krasske (1949), common in Lapland throughout the whole area studied. Quennerstedt (1955), sparse in two oligotrophic lakes in W Jämtland. Foged (1968), in 130 of the 203 localities, pH mostly 6.5–7.4, on the Varanger peninsula, N Norway. Klasvik (1974), common in the whole of Verkeån, in Scania, S Sweden. Foged (1980), in 17 of 38 localities on the limestone island of

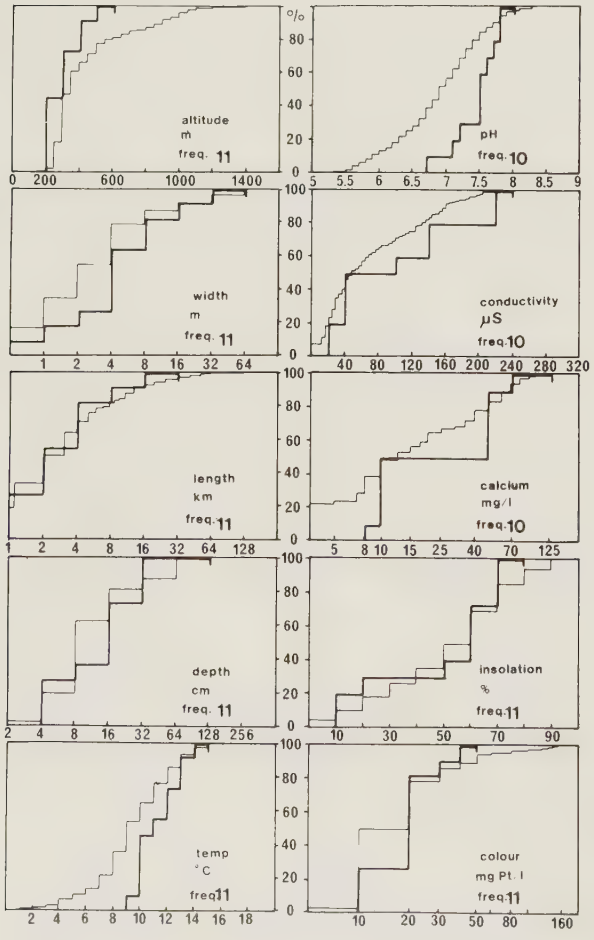


Fig. 51. *Gomphonema intricatum* v. *pumila*

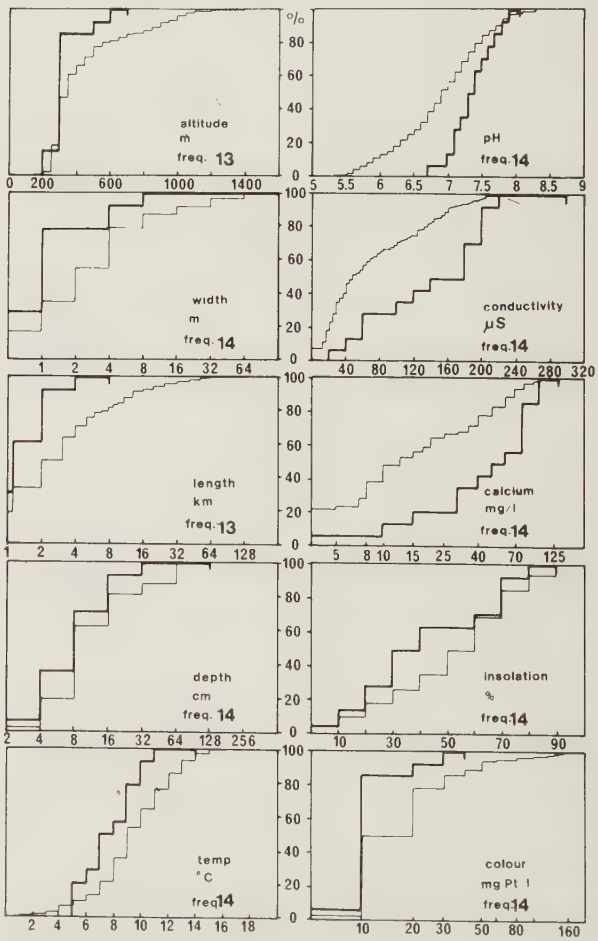


Fig. 52. *Meridion circulare*

Öland, S Sweden. Håkansson (1980), rather sparse in the estuary of the Kalix River. Warncke (1980), in 52 of the 196 localities in Jutland, Denmark. – (*Other countries*) Hustedt (1939), widely distributed and locally abundant, in the Pyrenees. Foged (1964), in 10 of the 34 localities, on Spitsbergen. Cholnoky (1968), pH optimum above 8, in S Africa. Foged (1973), in 20 of 30 localities, in SW Greenland. Sreenivasa & Duthie (1973), in many stations in the alkalic Grand River, Canada. Lawson & Rushforth (1975), in the upper parts of the Provo River, Utah. Eloranta & Kunnas (1979), extremely abundant and frequent, pH 6.3–6.6, 40–91 µS, in the Tourujoki river system. Johansson (1980), in the Narssaq area, S Greenland.

Navicula cryptocephala Kütz. v. *cryptocephala*

Ref.: Hustedt 1930 (p. 295, Fig. 496)

Habitat: Frequent alga which parameters follow the reference curve in most cases although pH, conductivity and calcium have higher values (Fig. 53).

Literature: (*Nordic countries*) Hustedt (1924), sparse in the Sarek Mts. Hustedt (1942), pH 6.2–9, 9.5–14.5° in ponds and rivulets, in the Abisko area. Krasske (1949), pH 6.5–6.8, in Kilpisjärvi area of Lapland. Quennerstedt (1955), in four oligotrophic lakes in W Jämtland. Foged (1968), in 27 of the 203 localities, pH 6.5–7.4, on the Varanger peninsula. Foged (1980), as alkaliphilous in 28 of the 38 localities on Öland. Håkansson (1980), frequent and rather abundant in the estuary of the Kalix River. Warncke (1980), in 124 of 196 springs in rather calcium-rich waters of Jutland. – (*Other countries*) Hustedt (1939), locally abundant otherwise sparse on mosses. Messikommer (1942), frequent in the high mountains of Davos. Wehrle (1942), large ecological amplitude, pH 3.0–8.5, resists heavy pollution in the Schwarzwald. Foged (1964), in nine of 34 localities, as alkaliphilous on Spitsbergen. Patrick & Reimer (1966), widely distributed in lakes, bogs or rivers; in fresh to slightly brackish water in central and eastern states of the US. Cholnoky (1968), pH optimum below 8, in S Africa. Foged (1973), in 13 of the 30 localities in SW Greenland. Sreenivasa & Duthie (1973), in many stations along the Grand River, pH 7.9–8.8, conductivity 260–375 µS, Canada. Benson & Rushforth (1975), in the moderately hard Huntington Canyon, Utah. Lawson & Rushforth (1975), throughout the Provo river system, Utah. Kawecka (1977), maximum development in the stream Rybi Potok, Tatra Mts. at 5.5°, pH 6.6 Eloranta & Kunnas (1979), in most stations, pH 6.3–6.6, 31–56 µS, 40–91 mg Pt/l, along the Tourujoki River. Fabri & Leclercq (1979), in many stations, 4–10°C, 39–116 µS, pH 3.4–6.0, in the rivers Verdre, Roer and Warche, Belgium.

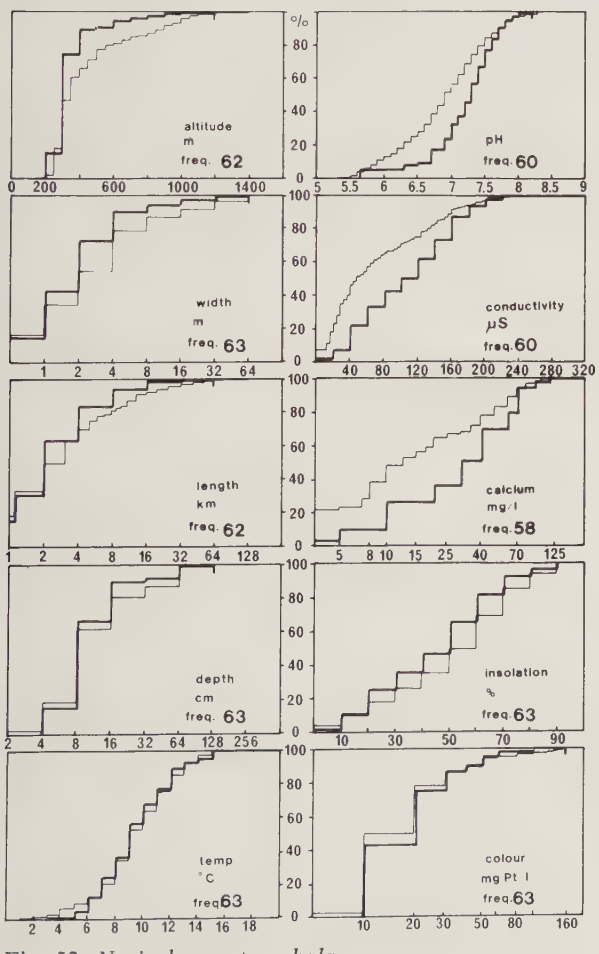


Fig. 53. *Navicula cryptocephala*

Navicula cryptocephala v. *veneta* (Kütz.) Rab.

Ref.: Hustedt 1930 (p. 295, Fig. 497 a)

Habitat: A very variable taxon in low altitude streams with high values of pH and conductivity, and <50 mg Pt/l; otherwise as the ref. curve (19 stations). Cliff substrate a little higher than the p.d., surroundings almost as the p.d. but no finds from alpine areas.

Literature: Hustedt (1939), abundant in most samples from the Pyrenees. Messikommer (1942), rare in the Schwarzwald. Foged (1964), in nine of the 34 localities, on Spitsbergen. Foged (1973), in three of the 30 localities in SW Greenland. Sreenivasa & Duthie (1973), as alkaliphilous in the Grand River, Canada. Benson & Rushforth (1975), in the moderate hard-water river in the Huntington Canyon, Utah.

Pinnularia interrupta W. Smith
Syn.: *Pinnularia biceps* Greg. v. *biceps*

Ref.: Cleve-Euler 1955 (p. 63, Fig. 1089 a, b)

Habitat: Most parameters seem to follow the ref. curve; but values for length of the streams, pH, conductivity, calcium, and colour are lower and insolation higher (only 7 records are available). Nearly 60 % are from alpine areas.

Literature: (*Nordic countries*) Krasske (1949), in five of the 11 localities in north Lapland. Quennerstedt (1955), common in the oligotrophic lakes in W Jämtland. Foged

(1968), in 58 of the 203 localities, mostly pH 6.5–7.4, on the Varanger peninsula. Foged (1980), from four localities on the limestone island of Öland. Håkansson (1980), few specimens in the estuary of the Kalix River. Warncke (1980), very few specimens in the streams on Jutland. – (*Other countries*) Messikommer (1942), frequent but not abundant in the high mountains of Davos. Foged (1964), in 7 of the 34 localities on Spitsbergen. Cholnoky (1968), a high pH optimum above 7 thus as other *Pinnularia* species which become abundant in acid waters, in S Africa. Foged (1973), in 19 of the 30 localities, in SW Greenland. Lawson & Rushforth (1975), sparse in the Provo River, Utah. Johansson (1980), few specimens in the Narssaq area, S Greenland.

Stauroneis phoenicenteron (Nitzsch.) Ehr.

Ref.: Hustedt 1930 (p. 255, Fig. 404)

Habitat: In streams below 700 m, rather large with high temperature and low calcium content compared to the ref. curve (only 7 localities). Silt as bottom substrate had higher values than the p.d., as also did alpine birch forest, mire and populated land.

Literature: (*Nordic countries*) Krasske (1949), rather frequent especially in ponds, pH 6.3–6.8, in northern Lapland. Quennerstedt (1955), frequent in the lakes studied in W Jämtland. Foged (1968), in 134 of 203 localities on the Varanger peninsula. Foged (1980), in 11 of the 38 localities on the limestone island of Öland. Håkansson (1980), very few specimens in the estuary of the Kalix River. Warncke (1980), in 22 of the 196 localities in the fairly calcium-rich springs on Jutland. – (*Other countries*) Wehrle (1942), frequent and abundant, β-mesosaprobic, in the Schwarzwald. Foged (1964), in 9 of the 34 localities on Spitsbergen. Patrick & Reimer (1966), wide range of ecological tolerance in the US. Cholnoky (1968), pH optimum 6.8 in S Africa. Foged (1973), in almost all localities studied in SW Greenland. Benson & Rushforth (1975), sparse in the upper parts of the Huntington Canyon, Utah. Lawson & Rushforth (1975), the most common *Stauroneis* species in the Provo River, Utah. Fabri & Leclercq (1979), in the River Roer, pH 6.0–7.4, 47–52 μS, the Hautes Fagnes, Belgium.

Synedra ulna (Nitzsch.) Ehr.

Ref.: Hustedt 1930 (p. 151, Figs. 158–159)

Habitat: One of the most frequent species in streams of the present study. All parameters closely follow the ref. curve (Fig. 54). Preference for alpine birch forest. Mass production in 15 streams.

Literature: A very common and abundant species in all types of habitats; only a few papers will be referred to. – (*Nordic countries*) Hustedt (1924), frequent and abundant in the Sarek area. Hustedt (1942), very abundant in some places in the Abisko area. Krasske (1942), pH 6.5–6.8, frequent in N Lapland. Quennerstedt (1955), in many of the oligotrophic lakes in W Jämtland. Foged (1968), in 114 of the 203 localities on the Varanger peninsula. Müller-Haeckel & Håkansson (1978), in a small stream near Abisko. Tangen et al. (1978), in a stream flowing into L. Øvre Heimdalsvatn. Eloranta & Kunnas (1979), pH 6.3–6.6, 31–56 μS, 40–91 mg Pt/l, abundand in the Tourujoki river system, Finland. Foged (1980), in 26 of the 38 localities on the limestone island of Öland. Håkansson (1980), up to 9 % of the total number of species in the estuary of the Kalix River. Warncke (1980), in 65 of the 196 in the fairly calcium-rich springs of Jutland.

Tabellaria fenestrata (Lyngb.) Kütz.

Ref.: Hustedt 1930 (p. 122, Fig. 99)

Habitat: Found at low altitudes, in broad and deep streams with high temperatures but low values of conductivity and calcium (Fig. 55); otherwise almost following the ref. curve. Preferring streams surrounded by spruce and pine forest.

Literature: A very common and widespread diatom. Only the most adequate literature has been referred to. – (*Nordic countries*) Hustedt (1924), frequent but not abundant in the Sarek Mts. Hustedt (1942), pH 6–9 and 7–15.5°,

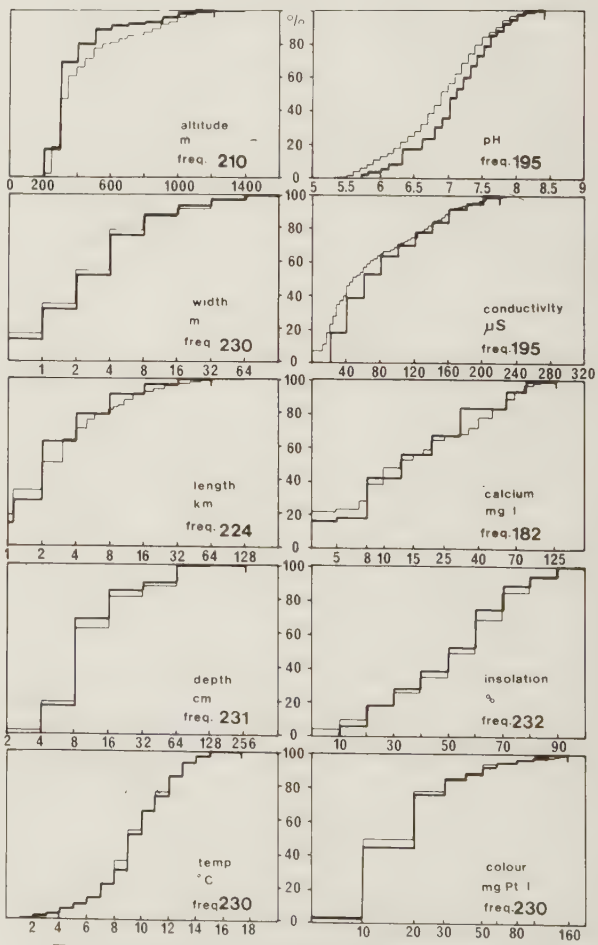


Fig. 54. *Synedra ulna*

few specimens in many types of habitats, in the Abisko area. Krasske (1949), frequent and abundant in lakes and ponds, pH 5.5–6.9, most occurring in streams with pH above 6.5 in N Lapland. Foged (1968), in 129 of the 203 localities on the Varanger peninsula. Müller-Haeckel & Håkansson (1978), pH 7.3–7.8 and 130–176 µS, in the small Njakajaurejokk near Abisko. Håkansson (1980), very abundant in the estuary of the Kalix River. Warncke (1980), very sparse in the springs on Jutland. – (*Other countries*) Wehrle (1942), in the litoral and pelagic in almost all types of waters. Cholnoky (1968), pH optimum not above 5.8. Foged (1973), frequent in SW Greenland.

Tabellaria flocculosa (Roth.) Kütz.

Ref.: Hustedt 1930 (p. 123, Fig. 101)

Habitat: Very frequent in Jämtland found in 210 stations. Most parameters follow the ref. curves but pH, conductivity, and calcium are significantly lower, while altitude, width and temperature are a little higher. Current velocity was found to have a mean value significantly higher than the mean value for whole of Jämtland (Johansson 1982).

Literature: A very common and widespread alga found in many types of waters. No literature will be referred to in this case since all reports given are of similar quality.

RHODOPHYTA

Batrachospermum moniliforme Roth.

Ref.: Sirodot 1884 (p. 209, Pl. 1–3, Pl. 2:1–5); Kylin 1912* (p. 15, Fig. 4); Bourrelly 1970 (p. 221, Pl. 54:3–6, Pl. 55:1–4)

Habitat: Found at 34 localities. Apparently favours small streams at low altitudes (Fig. 56). Temperature and pH-distributions correspond to the reference curve but conductivity and calcium are higher. Insolation poorer than the ref. curve, colour stronger. The f. *helminthoideum* (Kylin 1912) was first separated by Sirodot in 1884. It is probably not a well defined taxon and was therefore included in v. *moniliforme*. However, f. *helminthoideum* is locally easily recognizable by its confluent whorls. The ecology for this forma does not differ much from that of the typical f. of *B. moniliforme*, but the pH range begins at 6.5 instead of 4.8 for *B. moniliforme*. Calcium content as the ref. curve. Bottom substrate and surrounding vegetation with a few exceptions as the p.d.

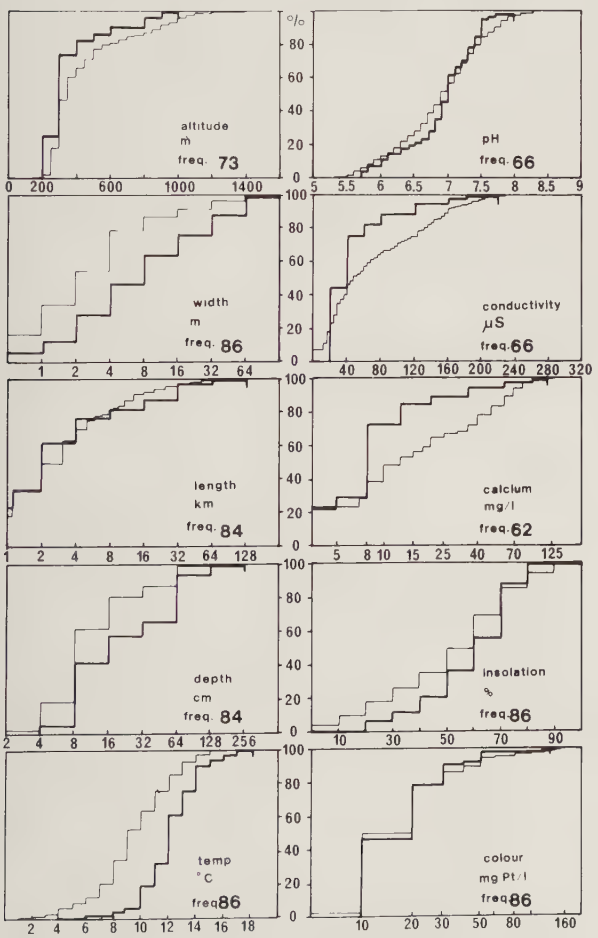


Fig. 55. *Tabellaria fenestrata*

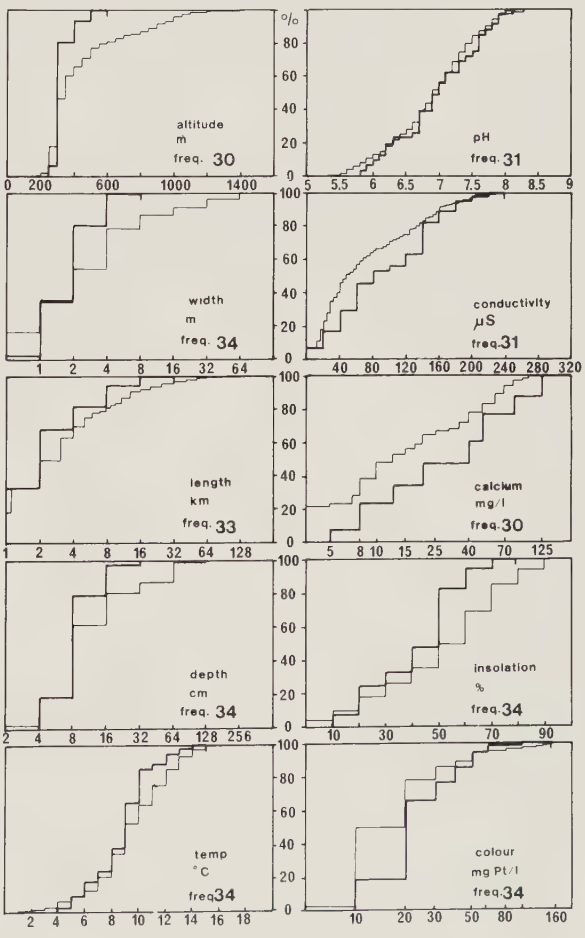


Fig. 56. *Batrachospermum moniliforme*

Literature: (*Nordic countries*) Israelson (1942), a common species found up to about 950 m (in the present study about 600 m). In other respects, his values on the ecology, such as conductivity 20–400 μS and calcium 2–50 mg/l (5–175 mg/l) shows concordance with mine. (*Other countries*) Kolkwitz (1950), as katharobic, oligosaprobic, and β-mesosaprobic. Sládeček (1973), as xeno- to β-mesosaprobic.

CYANOPHYTA

Stigonema mamillosum (Lyngb.) Ag.

Ref.: Geitler 1930–32 (p. 520, Figs. 320–24, 339); Starmach 1966* (p. 746, Fig. 1085–1087); Bourrelly 1970 (p. 355, pl. 93:1–4, 94:1)

The thallus form of *S. mamillosum* varies widely, especially in ramification. Several specimens have a cushion-like thallus, up to 1 cm high. Colour dull brown to blackish green.

Habitat: Apparently prefers rather wide watercourses at 500–900 m, with higher temperatures than for the ref. curve (Fig. 57); pH, conductivity and calcium content in the "*Stigonema* streams" much lower than for the ref. curves; insolation higher, to some extent due to the less efficient shading of wide watercourses; slightly lower water colour values than for the ref. curve; seems to prefer boulder bottoms and surrounding alpine heath and alpine birch forest.

Literature: Numerous records are available from all parts of the world, a small selection being mentioned below. (*Nordic countries*) Cedergren (1932), in many rivulets in the province of Härjedalen; Quennerstedt (1955), in the Långan river system; Skuja (1964), in a small tarn in the Kårsavagge, Abisko, growing well among blue-greens, desmids, and diatoms. – (*Other countries*) Hirano (1969), in rills from a glacier at 3700 m in the Himalayan Mts. Johansson (1976), on rock surfaces in craters at about 1000 m in the Azores. Johansson (1980), in an outlet of a lake located in a granite area in Kangerdluarssuq, S Greenland.

Rivularia biasolettiana Menegh.
Syn.: *Rivularia coadunata* (Sommerf.) Foslie

Ref.: Geitler 1930–32 (p. 650, Fig. 413); Starmach 1966 (p. 575, 867–869): Golubić 1967* (p. 56).

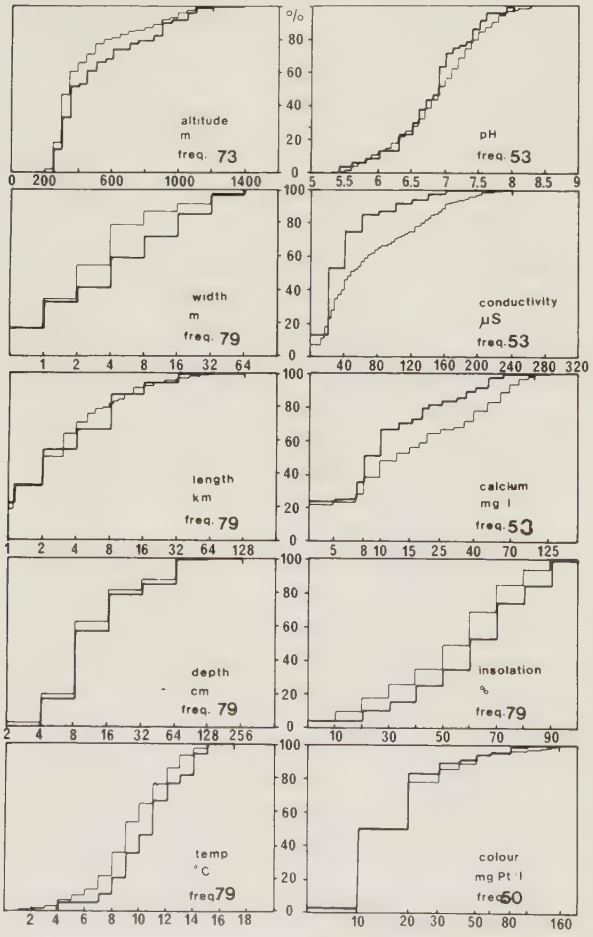


Fig. 57. *Stigonema mamillosum*

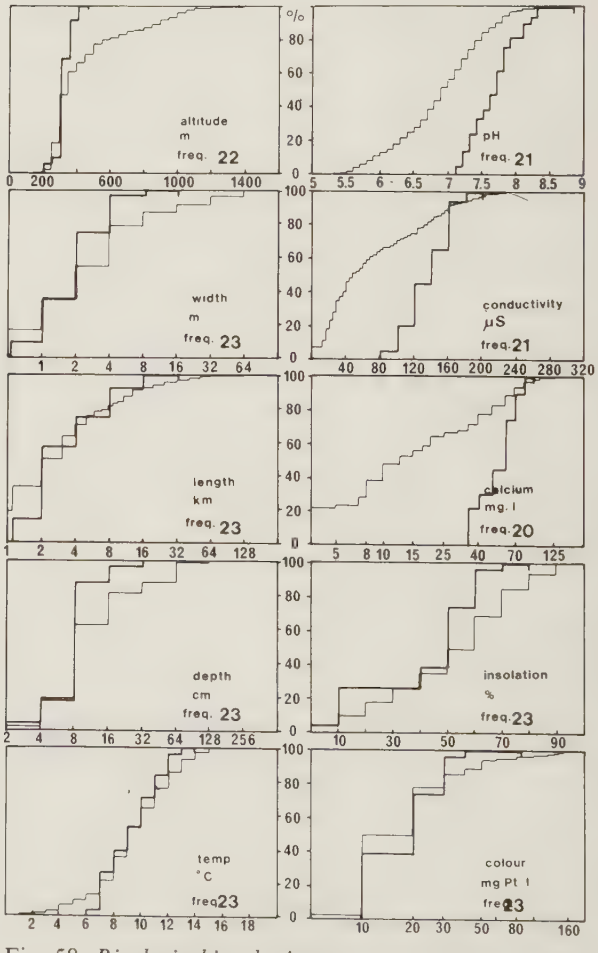


Fig. 58. *Rivularia biasolettiana*

Distinctions between several *Rivularia* species are difficult and unclear. Kann (1978) regards *R. biasolettiana* and *R. haematites* as the same species. In the present study the two taxa have been distinguished by the presence of layers in the algal crusts, so that tufts without layers of calcium carbonate are referred to as *R. biasolettiana* and those with are called *R. haematites*. The two species have different ecological preferences, but could be modifications of the same species.

Habitat: Most of the ecological parameters measured follow the ref. curve but conductivity and calcium seem to be lower and insolation a little higher (Fig. 58). *R. biasolettiana* is a common alga in Jämtland, found in about one stream in five and in about 20 % of these it is the dominating alga. It was found in almost equal amounts (%) in streams in alpine heath and subalpine birch areas on one hand, and in spruce and mixed forests on the other.

Literature: A very widespread alga and only a few of the references will be cited here. (*Nordic countries*) e.g. Skuja (1964), in Njakajaure mostly on stems of aquatic plants but also on other types of substrates. – (*Other countries*) Taylor (1928), abundant in rivulets on rocks, among mosses in waters with a low calcium content in the mountains of British Columbia. Geitler (1932), in stagnant and running waters, and also in the sea, on stones and aquatic plants, more rarely on wet soils.

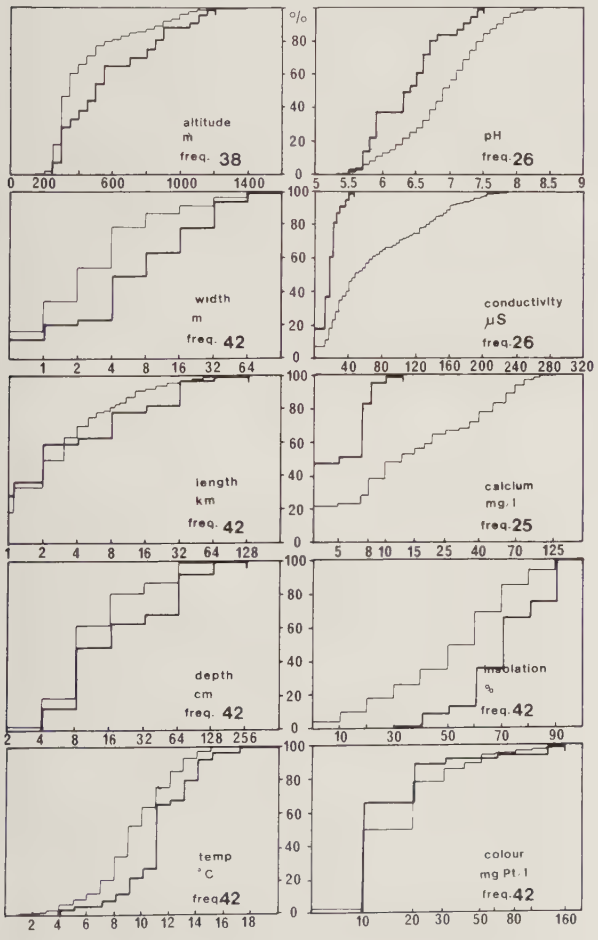


Fig. 59. *Rivularia haematites*

Rivularia haematites (D.C.) Ag.

Ref.: Geitler 1930–32 (p. 653, Figs. 45, 416, 417); Starmach 1966* (p. 579, Figs. 872, 873); Bourrelly 1970 (p. 410, Pl. 116:5, 117:1–3).

Difficult to distinguish from *R. biasolettiana*.

Habitat: In Jämtland the alga grew preferentially in small, low altitude watercourses with high pH, high conductivity, high calcium content, in more or less shaded habitats (Fig. 59). *R. haematites* was recorded in all types of habitats but never in montane areas which probably is due to low calcium content in many of the streams samples there.

Literature: Geitler (1932), in stagnant waters, rarely in running waters, on seepaged limestone and dolomite cliffs in the surf zone. Wehrle (1942), in lakes and rivers and seepaged cliffs in the Schwarzwald, Germany, where it seemed to be favoured by alkaline reaction. Fetzmann (1962), in waterfalls and on seepaged rocks with *Scytonema myochrous* building a community in the limestone and dolomite areas in Maltatal in the Austrian alps. Kann (1978), in some rivulets in Austria, very sensitive to high water level and high water velocity, many crusts being destroyed and recovering after 4–6 weeks.

3.2.3 Discriminant analysis for 53 algal taxa

A multiple discriminant analysis was used to see whether it was possible to make a linear combination of discriminating variables which might be used to indicate whether an alga would occur in a stream where the background variables are already known.

Method

For each of the alga observed in at least 20 streams a discriminant analysis was used (Program DISCRIMINANT in SPSS manual).

The "discriminant functions" are of the form:

$$D_i = d_{i1}Z_1 + d_{i2}Z_2 + \ldots + d_{ip}Z_p$$

where D_i is the score of the discriminant function i, the d's are weighting coefficients, and the Z's are the standardized values of the p discriminating variables used in the analysis. As a check of the adequacy of the discriminating functions, it is possible to classify the original set of cases to see how many are correctly classified by the variables being used. The procedure for classification involves the use of a separate linear combination of discriminating variables for each alga.

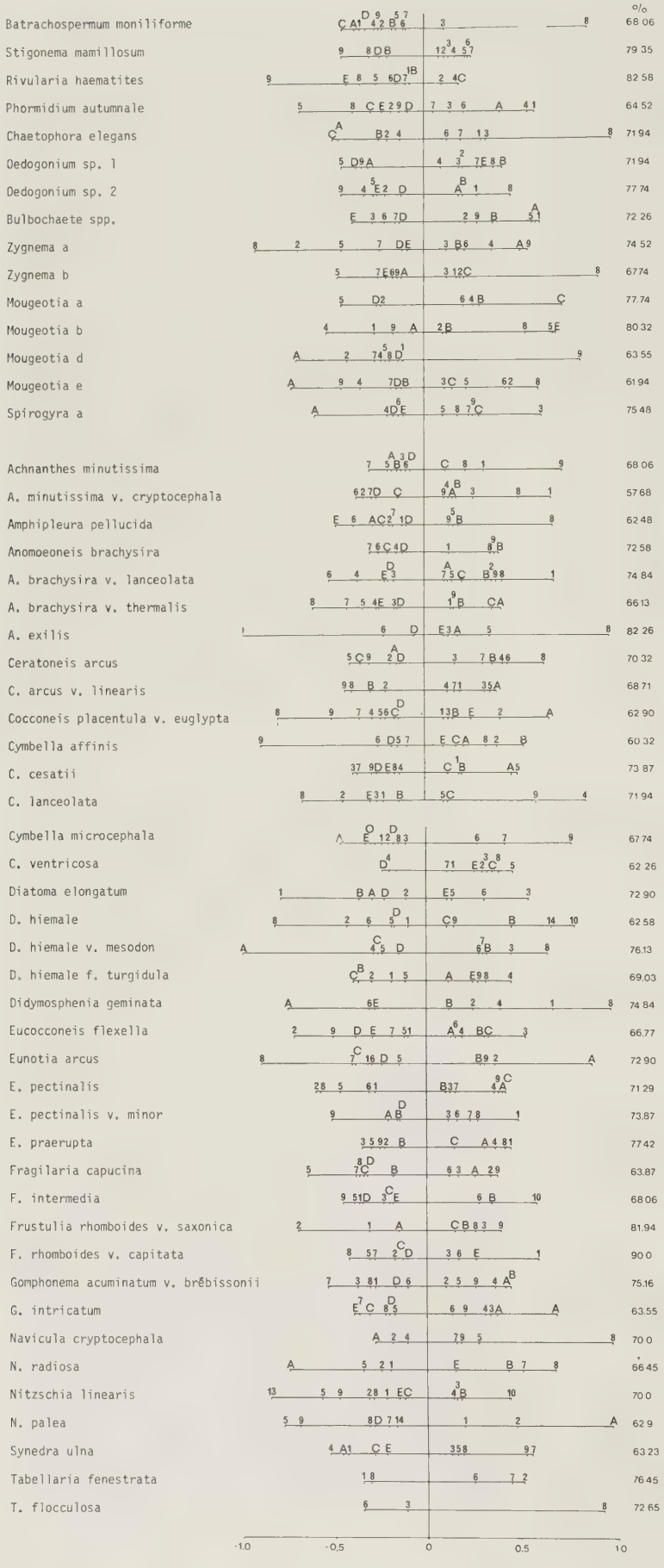

%
Batrachospermum moniliforme 68 06
Stigonema mamillosum 79 35
Rivularia haematites 82 58
Phormidium autumnale 64 52
Chaetophora elegans 71 94
Oedogonium sp. 1 71 94
Oedogonium sp. 2 77 74
Bulbochaete spp. 72 26
Zygnema a 74 52
Zygnema b 67 74
Mougeotia a 77 74
Mougeotia b 80 32
Mougeotia d 63 55
Mougeotia e 61 94
Spirogyra a 75 48
Achnanthes minutissima 68 06
A. minutissima v. cryptocephala 57 68
Amphipleura pellucida 62 48
Anomoeoneis brachysira 72 58
A. brachysira v. lanceolata 74 84
A. brachysira v. thermalis 66 13
A. exilis 82 26
Ceratoneis arcus 70 32
C. arcus v. linearis 68 71
Cocconeis placentula v. euglypta 62 90
Cymbella affinis 60 32
C. cesatii 73 87
C. lanceolata 71 94
Cymbella microcephala 67 74
C. ventricosa 62 26
Diatoma elongatum 72 90
D. hiemale 62 58
D. hiemale v. mesodon 76 13
D. hiemale f. turgidula 69 03
Didymosphenia geminata 74 84
Eucocconeis flexella 66 77
Eunotia arcus 72 90
E. pectinalis 71 29
E. pectinalis v. minor 73 87
E. praerupta 77 42
Fragilaria capucina 63 87
F. intermedia 68 06
Frustulia rhomboides v. saxonica 81 94
F. rhomboides v. capitata 90 0
Gomphonema acuminatum v. brébissonii 75 16
G. intricatum 63 55
Navicula cryptocephala 70 0
N. radiosa 66 45
Nitzschia linearis 70 0
N. palea 62 9
Synedra ulna 63 23
Tabellaria fenestrata 76 45
T. flocculosa 72 65
-1.0
-0.5
0
0.5
1.0

Fig. 60. Standardized discriminant function coefficients of 14 environmental factors in analysis of 53 taxa. Coefficients in the interval −0.05 to 0.05 are excluded. The method's applicability for the different taxa is expressed in percentages (to the right). The factors are, 1 altitude, 2 width, 3 length, 4 depth of the stream, 5 current velocity, 6 water discharge, 7 temperature, 8 conductivity, 9 pH, A calcium content, B colour, C nutrient supply, D water discharge, E insolation.

Results

Algae found in 20 or more streams are presented in Fig. 60. The variables measured are differentiated along the *x*-axis to see which of the variables are the most "important" to the alga.

The standardized discriminant function coefficient varied between −1 and 1, where the zero point for the continuum is the grand mean of all the classified cases, i.e., all the streams in which the alga was found and in those in which it was not. Altogether 53 algae were examined, 55 % of these had a prediction ratio of 70 % or above, which here has been considered adequate, indicating that the alga was placed in the right group with respect to the measured parameters. The results of variables with a skewed distribution (altitude, length, depth, conductivity, and colour) should be considered with caution.

The method and the variables measured worked very well in most cases, but either some of the algae seemed to be indifferent to the parameters measured or inadequate parameters were used. Results from algae with a prediction less than 65 % should be considered with caution (Table 10). The best discriminating variables measured for most algae were conductivity and calcium content, followed by altitude, current velocity, and pH. The method worked best for *Rivularia haematites* with a prediction of 82.58 %, *Mougeotia b* with 80.32 %, *Anomoeoneis exilis* with 82.26 %, *Frustulia rhomboides* v. *saxonica* with 81.94 % and *F. rhomboides* v. *capitata* with 90.0 %, see further Fig. 60.

Discussion

The main difference between the two methods is that the Kolmogorov approach gives either a positive or a negative relation to the different parameters, while the discriminant analysis gives an "importance" score for the variables in the discriminating function which makes the two methods very good when used together. The sign on the standardized discriminant function coefficients denotes whether the variable is making a positive or negative contribution, analogous to the interpretation of beta weights in multiple regression. For *Zygnema a* it could be stated that electrical conductivity is twice as important as pH on the first (and only) function. The discriminant analysis forms a good complement to the Kolmogorov statistics and knowledge of the importance of which variables should be measured and included in the classification.

To see to what extent dichotomized variables, such as type of surrounding vegetation and substrate, and missing values influenced the result of the discriminant analysis, six algae of different frequencies were used. Table 8 shows that the algae *Rivularia biasolettiana, Ceratoneis arcus, Tabellaria fenestrata, T. flocculosa* have higher prediction values (%) when missing values, as zeros, are included, while *Achnanthes minutissima* v. *cryptocephala* and *Amphipleura pellucida* have lower. The dichotomized variables included in both cases gave generally lower prediction in all cases, except *Achnanthes minutissima* v. *cryptocephala*. In this study the analyses were run with the dichotomized variables excluded but with the missing values included. The lower prediction values when missing values are included probably depends on the fact that the available variables are fewer, which naturally gives lower prediction. Since the dichotomized variables are measured in a subjective way with scales differentiating from all the other parameters, it was decided not to mix these two types.

For comparisons with other algal investigations on classifying algal species, Israelson (1949) is the most adequate source for Sweden. He divided the attached Zygnemales into four groups according to the concentration of electrolytes. Two main types are named after the characteristic components, the "*Vaucheria* type" and the "*Zygnema* type", respectively. Species involved in his four distributional groups (Table 9)

Table 8. The reaction of the discriminant analysis to missing values included as zeros (Option 1) and dichotomized variables (Option 2) in %.

	Frequency	not Opt 1	Opt 2 (not Opt 1)	Opt 1	Opt 2 (Opt 1)
Ceratoneis arcus	51	61.68	70.32	71.46	77.74
Rivularia biasolettiana	89	61.68	66.13	62.48	70.00
Tabellaria fenestrata	89	81.84	81.94	82.63	81.61
Tabellaria flocculosa	257	69.86	76.13	70.46	77.10
Achnanthes minutissima v. cryptocephala	285	57.68	61.29	39.92	36.13
Amphipleura pellucida	54	62.48	62.58	37.33	41.29

Table 9. Israelson's (1942) scheme of classifying Zygnemales.

Distributional Groups - The Zygnemales treated in the foregoing may be ranged with regard to their occurrence into the following groups

1. Restricted to waters more or less rich in electrolytes: Spirogyra e (- S. maxima p.p. at least), Spirogyra b (- p.p. S. cf. velata).
2. Preferring waters rich in electrolytes. Spirogyra c (= S. cf. fluviatilis).
3. No clear preponderance in any particular kind of water: Mougeotia b and d, Zygnema c.
4. More or less exclusively restricted to waters very poor in electrolytes
   a. Distributed all over Scandinavia: Mougeotia a, c, and e, Mougeotiopsis calospora, Spirogyra d, Zygnema a and b.
   b. With a northern distribution: Zygnema melanosporum, Spirogyra lapponica, and Spirogyra a (- S. lapponica?).

Table 10. The discriminating variables used in the discriminant analysis applied on the most frequent algae (53 species). l.p. = low prediction (<65 %).

Altitude	Size of stream	Velocity	Discharge
Phormidium autumnale (l.p.)	Zygnema a	Phormidium autumnale (l.p.)	Achnanthes minutissima v. cryptocephala
Bulbochaete spp.	Spirogyra a	Oedogonium sp. 1	Amphipleura pellucida (l.p.)
Achnanthes minutissima v. cryptocephala (l.p.)	Oedogonium sp. 2	Zygnema b	Anomoeoneis brachysira v. lanceolata
Anomoeoneis brachysira v. lanceolata	Cymbella cesatii	Mougeotia a	
Diatoma elongatum	C. lanceolata	Mougeotia b	
Didymosphenia geminata	Diatoma elongatum	Ceratoneis arcus	
Eunotia praerupta	Eunotia flexella	C. arcus v. linearis	
Frustulia rhomboides v. capitata	E. pectinalis	Cymbella cesatii	
Gomphonema intricatum (l.p.)	Tabellaria fenestrata	C. ventricosa (l.p.)	
Tabellaria fenestrata		Eunotia pectinalis	
		Fragilaria capucina (l.p.)	
		Nitzschia palea (l.p.)	
		N. linearis	

Temperature	Conductivity	pH	Calcium content
Anomoeoneis brachysira	Batrachospermum moniliforme	Rivularia haematites	Bulbochaete spp.
Cymbella cesatii	Oedogonium sp. 1	Zygnema a	Mougeotia d (l.p.)
Frustulia rhomboides v.capitata	Oedogonium sp. 3	Mougeotia d (l.p.)	Mougeotia e (l.p.)
Gomphonema intricatum (l.p.)	Zygnema a	Achnanthes minutissima	Spirogyra a
Achnanthes minutissima	Zygnema b	Anomoeoneis exilis	Anomoeoneis brachysira v. thermalis
	Mougeotia e	Cymbella affinis (l.p.)	Cocconeis placentula v. euglypta (l.p.)
	Amphipleura pellucida (l.p.)	C. microcephala	Cymbella microcephala
	Anomoeoneis brachysira v. thermalis	Eunotia pectinalis v. minor	Diatoma hiemale (l.p.)
	Anomoeoneis exilis	Fragilaria capucina (l.p.)	D. hiemale v. mesodon
	Ceratoneis arcus	Frustulia rhomboides v. saxonica	Didymospenia geminata
	Cocconeis placentula v. euglypta (l.p.)	Nitzschia palea (l.p.)	Eunotia arcus
	Cymbella lanceolata		Fragilaria intermedia v. brebissoni
	Diatoma hiemale v. mesodon		Nitzschia palea (l.p.)
	Didymosphenia geminata		N. linearis
	Eunotia arcus		
	E. pectinalis		
	Frustulia rhomboides v. capitata		
	Navicula cryptocephala		
	N. radiosa		
	Tabellaria flocculosa		

Colour	Nutrient supply	Water supply	Insolation
Oedogonium sp. 1	Rivularia haematites	Nitzschia linearis	Oedogonium sp. 2
Anomoeoneis brachysira	Chaetophora elegans		Bulbochaete spp.
Cymbella affinis (l.p.)	Mougeotia a		Mougeotia b
Gomphonema acuminatum v. brebissoni			Amphipleura pellucida (l.p.)

correspond to results of the present study, with the exception of *Spirogyra c* which does not seem to prefer electrolyte-rich waters in this survey. Neither *Mougeotia a* and *e*, or *Spirogyra d* seem to be exclusively restricted to waters very poor in electrolytes.

According to Table 10, the algae are divided with regard to their individual most adequate environmental factors. Some reports in the literature are available for comparisons. Whitton (1975) has carried out a literature review treating attached algal species in relation to different environmental factors:

High current velocity is connected with the principal parameter of importance for the presence of *Lemanea* spp. (Israelson 1942) but also, according to Whitford (1960 b), to the presence of *Oedogonium* spp. (all year), and *Chaetophora* (summers). *Lemanea* was not included in the discriminant analysis in the present study since its frequency was less than 20 stations but nevertheless it occupies fast-flowing streams.

Temperature was another factor considered by Whitton (op. cit.); here the well-known cold-water species, e.g. *Hydrurus foetidus* and *Diatoma hiemale*, were mentioned. In Jämtland *Diatoma hiemale* v. *mesodon* is included in the algal group found in "small cold streams" (type 5 in Chapt. 3.2.1).

Light climate, here called insolation, discriminated greatly in favour of genera like *Oedogonium* and *Bulbochaete* since they prefer habitats with high insolation. *Cladophora glomerata*, a green alga with luxuriant growth, is also found in well-illuminated reaches of streams (Whitton 1970). Other light demanding species are *Ceratoneis arcus* and *Ulothrix zonata* (Sherman & Phinney 1971); the former being found together with v. *linearis* in streams with low pH, conductivity, and calcium content in Jämtland. Species preferring dark habitats are

mostly found among the red algae, e.g. *Batrachospermum* spp., *Lemanea* spp. (Israelson 1942; Gessner 1955; Rider & Wagner 1972) but also among diatoms, e.g. *Amphipleura pellucida* (Johansson 1982).

Chemical measurements (pH, conductivity, calcium content) are often summarized as different types of saprobic systems (e.g. Kolkwitz & Marsson 1908; Liebmann 1951; Sládeček 1973) but in the context of Jämtland these are often inexact, and most species from north Sweden are classified as oligotrophic, oligosaprobic, etc. and little distinction has been made between species. Some of the red algae in Jämtland prefer streams with rather high conductivity, e.g. *Batrachospermum moniliforme*, its forma *helminthoideum* and *Lemanea fluviatilis*, while in Israelson (1942) they are listed as species occurring in different kinds of waters, irrespective of the amount of electrolytes. It should be kept in mind that this is related to the whole of Sweden while *Batrachospermum moniliforme* in some places in Jämtland reaches its border of distribution.

The Kolmogorov distribution curves for the different species related to a reference curve have also been applied on phytoplankton species from a survey of 1250 small and medium-sized lakes in Sweden (Rosén 1981).

3.3 Multivariate approaches

Altogether data on 316 algae and 16 environmental parameters were collected from 501 stations. The treatment of these data proceeded in 4 steps:

(a) Statistics on the distribution of each alga in the set of stations in relation to the environmental parameters. This treatment resulted in an autecological survey of attached algae (Chapter 3) and an annotated list of attached algae occurring in Jämtland streams with notes on their ecology, see Johansson (1982).

(b) Detection of associations between algal species and underlying environmental gradients, and erection of species groups. The species groups were checked with the autecological survey and a system of ecological indicator groups established (Chapt. 4).

(c) Overall classification and ordination of the stations. With a clustering technique and tabular rearrangement of the stations on the basis of their floristic similarities, a classification of attached algal communities was attempted.

(d) A principal components analysis was used to study the environmental gradients underlying the variation in communities (Chapter 5).

4. Species association

The measures of species association based on records of presence or absence were carried out on the species found in Jämtland. Numerous ways of expressing the degree of association between two species are available (Müller-Dombois & Ellenberg 1974, p. 212). In this case the phi (ϕ) coefficient, was used:

$$\phi_{(X,\ Y)} = \frac{A \cdot D - B \cdot C}{\sqrt{(A+B)\ (A+C)\ (B+D)\ (C+D)}}$$

where, X and Y are the two algae to be compared.
A number of streams, where both algae have been found
B number of streams, where alga X has been found but not Y
C number of streams, where alga Y has been found but not X
D number of streams, where neither alga X nor Y have been found

On the basis of the matrix of the association index (ϕ) values, three multivariate analyses were carried out: Cluster analysis and factor analysis on species only, and a factor analysis on both species and environmental parameters.

4.1 Cluster analysis of species

In all clustering procedures it is essential that the entities within a group show more likeness to each other than to entities of other groups. This relates to the situation of relative homogeneity towards the surroundings. Discontinuities in the field should not be confused with those in abstract typologies. They are in fact independent and it is also possible that easily definable phytocoenoses are difficult to classify because they form a continuum in a multivariate analysis.

Method

From the phi matrix of the 133 species present in more than five streams a cluster analysis was carried out. The computations leading to the construction of the dendrogram are as follows:

(1) The computer scans the established phi matrix for the highest IS (index of similarity) value (here phi coefficient) and then isolates the stand-pair that shares this value. The information of the two species with the highest IS value is stored.

(2) Then, the two species selected first are combined into a synthetic "superspecies". This is done by averaging the quantitative values of each station of the two species.

(3) The synthetic or mean species is returned to the IS matrix in place of one of the two individual species. The place arbitrarily chosen is that of the species with the smaller number while the position of the species with the larger number is cancelled in the matrix.

(4) Now, a new series of IS values is calculated for the synthetic species.

(5) The computer then scans the modified similarity matrix again for the highest IS value.

(6) Again a new synthetic species is computed and the second synthetic species is entered into the second matrix.

(7) The computation cycle (algorithm) is now continued by first calculating the new IS values for all remaining values with the second synthetic species; thereafter the computer scans the modified matrix again for the highest value and selects the two species that share this value.

Results

This analysis groups the species at different association levels. Here the species are shown as clusters of pairs linked together at certain levels of association. The clusters of pairs are further combined into more inclusive or generalized clusters that form a hierarchical arrangement.

Generally very low association values were found. The highest value, 0.514, was found between *Vaucheria* spp. and *Meridion circulare*. Most species-pairs have phi values around 0.23 and whole clusters around 0.10 (Fig. 61) which gives 9 clusters.

Since the paired and grouped species clusters in the dendrogram are the result of linkages at various levels of similarity, an ecologically meaningful classification is not automatically indicated. But, classification can be automated by the setting of more or less arbitrary threshold values. In this case, however, the clusters were chosen in connection with

Table 11. Results of the cluster- and factor analysis on species resemblance.

	Type 1 (Cluster 2)	Type 2 (Cluster 3)	Type 3 (Cluster 6)
Characteristic features:	high insolation high velocity low conductivity pH around 6 low calcium	no specific	slight moderate current high conductivity high calcium content
Habitats:	alpine heaths clear cut areas light mixed forests mires	all types	lowland spruce forests
Indicators:	Oedogonium sp. 1+2 Bulbochaete spp. Anomoeoneis brachysira v. lanceolata Tetraspora gelatinosa Stigonema mamillosum Frustulia rhomboides v. saxonica Anomoeoneis brachysira Tabellaria flocculosa	Ceratoneis arcus v. linearis Cymbella ventricosa Gomphonema acuminatum v. brebissonii Achnanthes minutissima v. cryptocephala Cymbella affinis Synedra ulna	Nostoc spp. Oscillatoria tenuis Amphipleura pellucida Cocconeis placentula v. euglypta Navicula cryptocephala N. radiosa

the results in the factor analysis also on single species (see below) so that three ecologically meaningful groups of species were the most appropriate result. These clusters are 2, 3 and 6 (Table 11). Type 1 was dominated by *Oedogonium* and *Bulbochaete* and the factors most connected with this algal group were stations with high insolation, high current velocity, low calcium content, and conductivity such as streams in alpine heaths, clear-cut areas, etc. Type 2 (= Cluster 3) was dominated by *Achnanthes minutissima* v. *cryptocephala* and *Cymbella affinis*, found in all types of undisturbed areas. Type 3 (= Cluster 6) was dominated by *Nostoc* spp., found in streams in lowland spruce forests.

4.2 Factor analysis on species

Factor analysis can be characterized as a statistical method aimed at estimation of the underlying common covariance structure of a multivariate normal population. In this respect factor analysis differs from component analysis (see Chapt. 5) which is a variance-oriented method of summarization. Both factor analysis and components analysis, when used in stochastic models, require the assumption that the underlying joint probability distribution is multivariate normal, and that the variates are commensurable.

The basic model in factor analysis can be given by the expression $x_i = \Sigma a_{ij} \sqrt{j} + e_i$ which implies that each observed variate x_i is considered to be a composite of the effect of m common factors $\sqrt{j}$, $j = 1 \ldots m$ and a specific factor e_i. The symbol a_{ij} represents factor loadings. It follows from this definition that the basic computational problem actually amounts to finding the factor loadings and the variances of the specific factors. In contrast with the extraction of component scores in component analysis, the factor scores (coordinates) cannot be derived by a simple linear transformation in factor analysis (Orlóci 1973).

Method

The three ordinary steps are (1) preparation of the correlation matrix, (2) extraction of the initial factors—exploration of possible data reduction, and (3) rotation to a terminal solution—the search for simple and interpretable factors. The different steps in the computer program used (BMD) are:

1. Correlation matrix (based on phi coeff. in this case).
2. The eigen values of the factors are listed. The criterion for the number of factors is the number of factors with eigen values greater than one.
3. Unrotated factor loadings (pattern) for principal components. These loadings are the eigen vectors of the correlation matrix multiplied by the square roots of the corresponding eigen values.
4. Orthogonal rotation is performed. Gamma is preassigned to 1 because varimax rotation is performed.
5. Rotated factor loadings—coefficients of the factors after rotation.
6. Sorted rotated factor loading.
7. Factor score coefficients. The rotated factor loadings are multiplied by the factor correlations to obtain the factor structure.
8. Factor scores are obtained by multiplying the standard

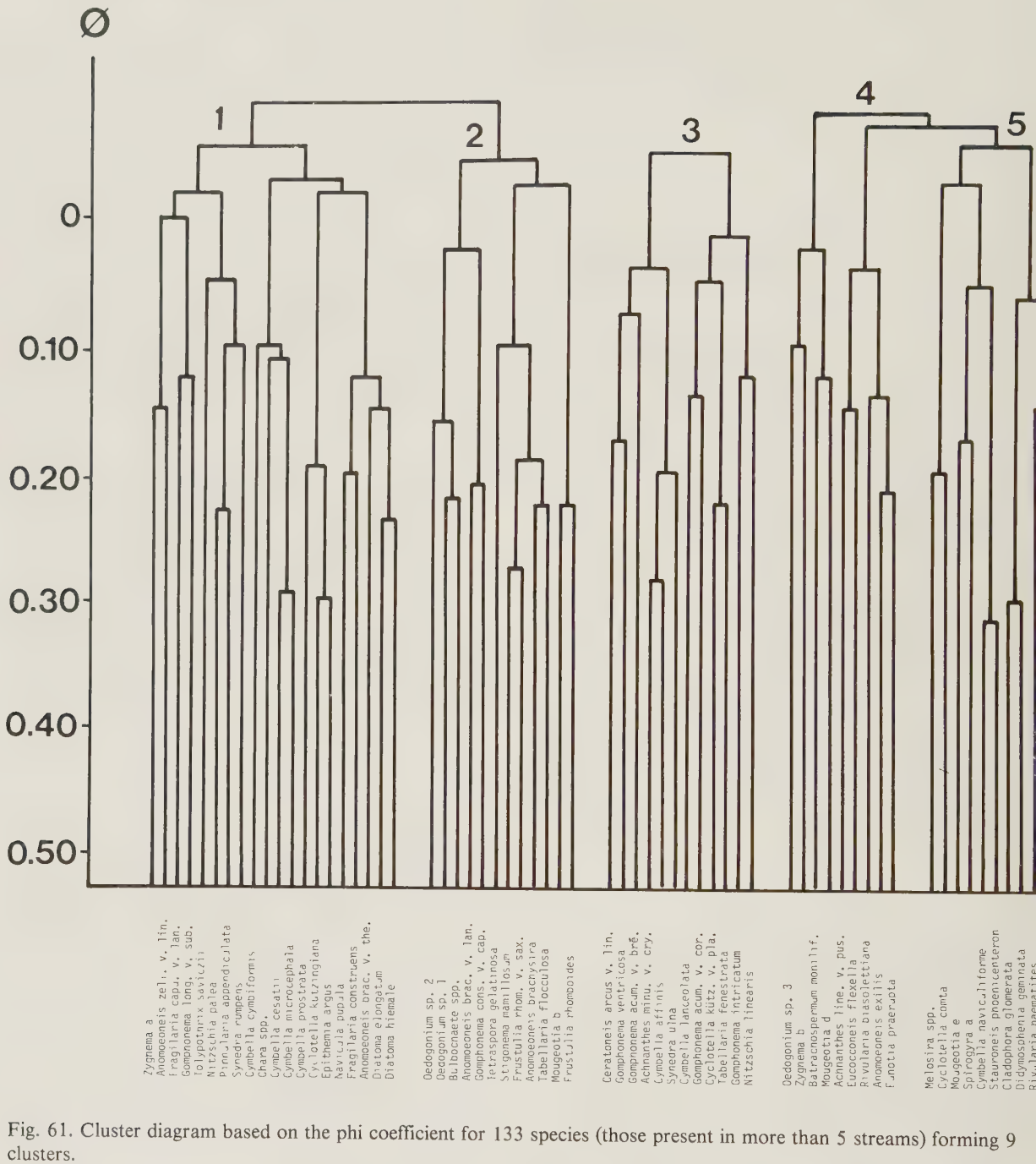
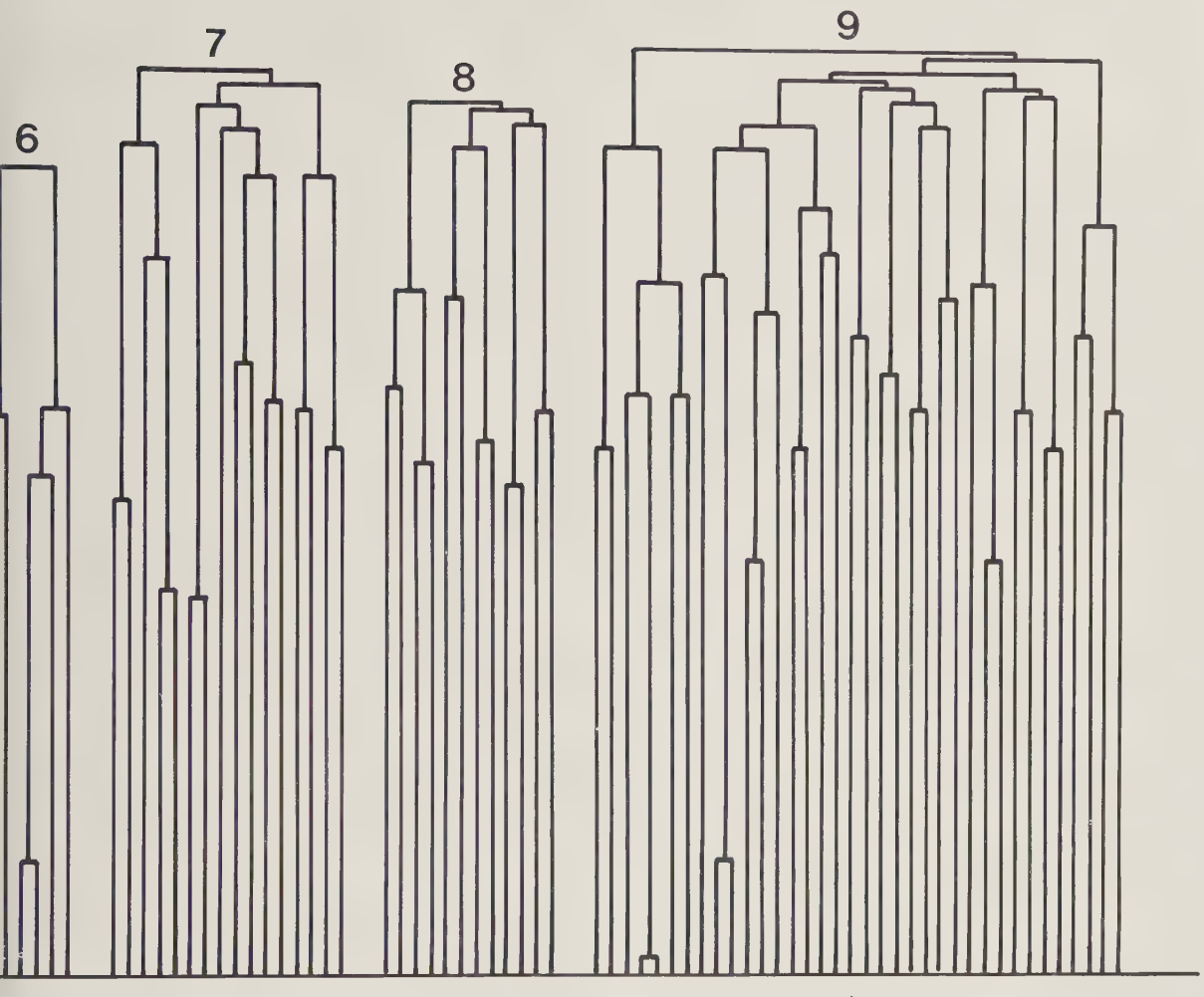


Fig. 61. Cluster diagram based on the phi coefficient for 133 species (those present in more than 5 streams) forming 9 clusters.


6
7
8
9
Oscillatoria tenuis
Amphipleura pellucida
Cocconeis plac. v. eug.
Navicula cryptocephala
Navicula radiosa
Ceratoneis arcus
Gomphonema olivaceum
Chaetophora elegans
Navicula amphibola
Amphora ovalis
Eunotia lunaris
Zygnema c
Achnanthes kryophila
Fragilaria capucina
Gomphonema angustatum
Navicula rhyncocephala
Eunotia pectinalis
Eunotia pect. v. min.
Eunotia bidentula
Closterium spp.
Denticula tenuis
Navicula bacillum
Cocconeis placentula
Acnnanthes minutissima
Ulothrix zonata
Cymbella aspera
Anomoeoneis exil. v. lan.
Synedra ulna v. dan.
Cymbella delicatula
Diatoma hiem. f. tur.
Nitzschia dissipata
Achnanthes lanceolata
Draparnaldia glomerata
Fragilaria intermedia
Chantransia sp.
Vaucheria spp.
Meridion circulare
Diatoma hiem. v. mes.
Navicula gracilis
Mougeotia a
Microspora palu. v. min.
Eunotia arcu. v. fal.
Diatoma vulgare
Fragilaria cons. v. ven.
Navicula cryp. v. ven.
Frustulia rhom. v. cap.
Gomphonema long. v. subcl.
Eunotia arcus
Synedra acus
Batrachospermum moni. f. hel.
Lemanea fluviatilis
Oedogonium sp. 4
Cymbella cistula
Spirogyra d
Cymbella gracilis
Microspora amoena
Acnnantnes linearis
Tolypothrix penicillata
Cymbella aequalis
Pinnularia interrupta
Oscillatoria irrigua
Spirogyra c
Gomphonema intr. v. pum.
Tolypothrix sp.
Batrachospermum monilif.
Prormidium autumnale
Spirogyra b
Navicula sp

scores for the original variables by the factor score coefficients.

9. The result is illustrated as plots of the factor scores; one factor against the other.

Results

The first eight factors explained 13 % of the total amount of information. If this had been illustrated the species would have been scattered all over the diagram of the two first factors. Many species concentrate around the origin or are often scattered without clear clustering aggregations, which means that most species do not have distinct ecological preferences as far as the included environmental factors are concerned. The different species' mean values of the 12 parameters did not give any distinct gradients.

Conclusions

This result was checked with rotation of the clusters of species with the position of species along the axis and upon which final groupings on a double basis were decided (Table 11). Clusters 2, 3 and 6 were found as aggregations of species in the FA. Cluster 2 or the *Oedogonium* - *Bulbochaete* group is characterized by indicator species preferring high insolation, high current velocity, low conductivity, pH around 6 and low calcium content. Cluster 3, or the *Achnanthes* - *Cymbella* group, seemed in this analysis to have no special preferences and can invade most habitats. Cluster 6, or the *Nostoc* group, seem to prefer lowland spruce forest streams with slow to moderate current velocity, high conductivity, and rather high calcium content.

4.3 Factor analysis of species and environmental factors

Method

The program (BMD) was also used for the 133 species as well as for 14 environmental variables. Eight factors were rotated. The highest values of the different parameters in the rotated factor matrix on each factor were compared with the highest factor score for the 133 algae from the eight factors extracted.

Results

Six algal groups with corresponding ecological factors were established:

Rivularia haematites group with accompanying algae like *Oscillatoria irrigua* and *Cladophora glomerata*; associated environmental factors were a surrounding vegetation of arable land with high nutrient content and streams with high contents of calcium and magnesium.

Cyclotella kützingiana, C. kützingiana v. *planetophora, Anomoeoneis brachysira* v. *lanceolata*, and *Pinnularia interrupta*, in a group found mostly in large streams surrounded by spruce forests.

Navicula amphibola, N. pupula, Amphora ovalis, Oscillatoria tenuis, and *Microspora palustris* v. *minor*, in a group found in streams with silt bottom, high current velocity, often running through mires.

Anomoeoneis zellensis v. *linearis, Tolypothrix saviczii, Frustulia rhomboides, F. rhomboides* v. *saxonica* and v. *capitata*, in a group found in streams in alpine regions, running mostly through alpine heath with high insolation.

Tetraspora gelatinosa, Gomphonema constrictum v. *capitata, Cocconeis placentula*, and *Synedra rumpens*, in a group found in streams running through deciduous forests.

Microspora palustris v. *minor* and *Gomphonema angustatum*, in a group found in brown coloured streams running through pine forest.

Discussion

Most numerical methods treated in this way deal with station resemblance but some have been found dealing with the datasets on a species basis: Amspoker (1977) deals with diatoms in an estuary where the multinumerical approaches give distinct clusters due to parameters such as salinity and the stability of the substrate. The ecology of the different species was evaluated with a discriminant analysis. Descy (1976), in two Belgian streams, ordinated the diatoms and the ecological parameters mainly treated in this study (Chapt. 4.4). Since many species and ecological parameters used are different, comparisons with different algal preferences are almost impossible.

Leclercq (1977) used a principal component analysis on algal species in two streams and got a

fairly good grouping of the algae along factor 1, with acidophilous species such as *Eunotia exigua, E. tenella, E. lunaris, E. angustata, Pinnularia viridis* v. *sudetica*, and *Frustulia rhomboides* v. *saxonica*. These species coincide with Johansson (1982) and four algal associations were recognized: *Eunotia exigua - Pinnularia subcapitata* association, *Diatoma hiemale - Meridion circulare* ass., *Vaucheria* ass. In comparison with the present study the ecological preference of the algal species coincide with the annotated list of species (Johansson 1982). Most *Eunotia* species are found in Cluster 7 in the cluster analysis and in clusters 4 and 14 in the TABORD run (Chapt. 5.2.1), which indicate alpine streams with low pH and calcium content.

5. Station resemblance

5.1 Factor analysis applied to the 501 stations

To get an ordination (Chapt. 5.2) of the 501 stations the same BMD program was applied as used for the FA of the species (Chapt. 4). Here eight factors were calculated and only presence-absence data were used according to Chapt. 4.

The stations with the highest factor scores were found for each factor and the corresponding species as factor loadings in a rotated factor matrix.

Results

The factor loadings and factor scores varied in numerical values. The species and stations were found at the following limits:

Factor	*Factor loading (species)*	*Factor score (stations)*
1	0.3	3
2	0.2	1.5
3	0.4	2.4
4	no adequate results	
5	0.25	2.9
6	0.25	3
7	0.3	3
8	0.3	4

These eight factors make up only 16.2 % of the total variance, probably depending on the character of the organisms which seem to survive everywhere and/or further adequate parameters should have been incorporated.

The following types were found:

Type 1. Characterized by alpine streams and their attached algae, two different groups of indicators were found:
(a) (High scores and loadings in relation to factor 2) Ecological characteristics: high altitude streams, low values of calcium and conductivity, bottom of boulders and stones. Indicators: *Frustulia rhomboides* v. *saxonica, Tabellaria flocculosa.*

(b) (High scores and loadings in relation to factor 7) Ecological characteristics: high altitude, mostly small streams, low conductivity, pH 6 to 7, very low calcium values, high insolation, alpine heath. Indicators: *Oedogonium* sp. 1, *Mougeotia b, Anomoeoneis brachysira, Eunotia lunaris, Frustulia rhomboides* and its v. *saxonica, Tabellaria flocculosa.*

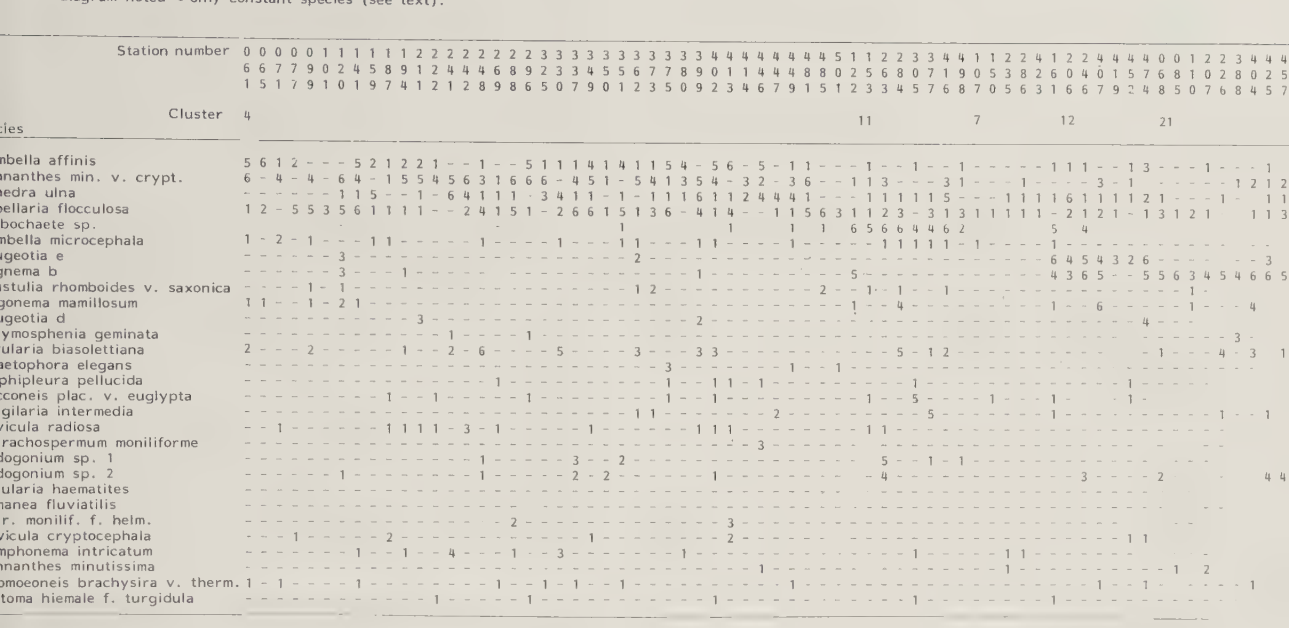
Type 2. (High scores and loadings in relation to factor 1) Ecological characteristics: lowland streams, low current velocity, large streams, high water-temperature, not coloured water. Indicators: *Cyclotella kützingiana, Cymbella cesatii, C. microcephala. Tabellaria fenestrata.*

Type 3.
(a) (High scores and loadings in relation to factor 3) Ecological characteristics: No special preferences. Indicators: *Achnanthes minutissima* v. *cryptocephala, Ceratoneis arcus, C. arcus* v. *linearis, Cymbella affinis, C. ventricosa, Gomphonema acuminatum* v. *brebissonii, Synedra ulna, Tabellaria flocculosa.*
(b) (High scores and loadings in relation to factor 6) Ecological characteristics: Undisturbed surrounding habitats, with pH $\geqslant$ 7. Indicators: *Cocconeis placentula, Cymbella affinis, Denticula tenuis, Diatoma vulgare, Achnanthes flexella, Fragilaria construens* v. *venter, Navicula bacillum.*

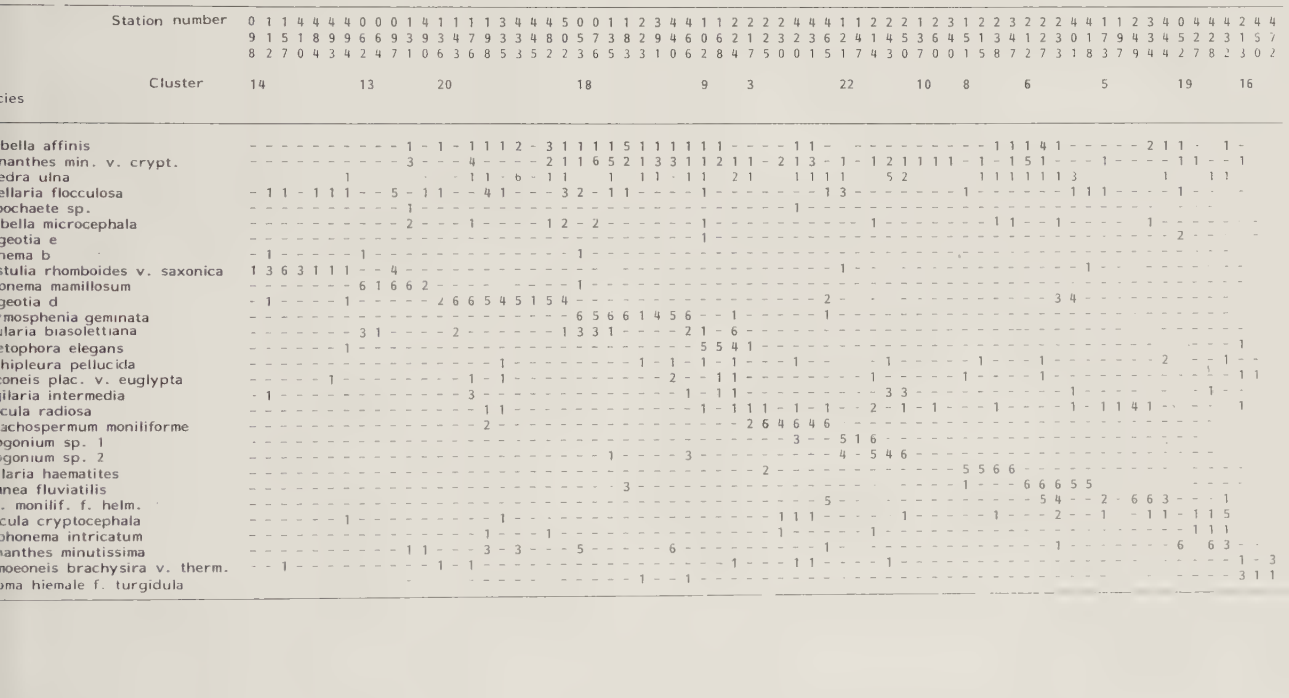
Type 4. (High scores and loadings in relation to factor 5) Ecological characteristics: large streams, high current velocity, rather low values of conductivity and calcium content. Indicators: *Rivularia biasolettiana, Zygnema b, Spirogyra a, Anomoeoneis exilis, A. brachysira* v. *lanceolata, Cymbella ventricosa, Eunotia praerupta.*

Type 5. (High scores and loadings in relation to factor 8) Ecological characteristics: lowland, high calcium and conductivity values, small streams, cold temperature. Indicators: *Chantransia* sp., *Vaucheria* sp., *Cymbella prostrata, Diatoma hiemale* v.

le 12. Classification of 135 selected stations into 18 clusters (of algal assemblies) obtained by means of TABORD; only the upper part of the complete diagram noted ~ only constant species (see text).



le 12 (contin.)



mesodon, Meridion circulare, Nitzschia angustata v. *acuta*.

5.2 Ordination and classification of subsets of the whole dataset

van der Maarel (1979) describes phytosociological ordination as the procedure of arranging phytosociological entities along the axis of variation in a uni- or multi-dimensional scheme according to the relations between entities.

5.2.1 The TABORD method

To be able to include all algae (316) and all stations (452 in this case) in the TABORD program it was necessary to split the dataset into five parts (88 stations/159 species, 90/168, 89/186, 90/163, 91/164). From each of the selected parts a table was produced and a selection (135/214) of the whole dataset was run in the same manner to see whether it could be representative of the whole dataset (Table 12).

Method

The TABORD program (van der Maarel et al. 1978) is essentially a clustering procedure based on relevé (here = station) similarity, combined with a procedure for obtaining a diagonal structure of clusters in the table. The program includes the following steps: Establishment of initial clusters, relocation, measurement of (dis)similarity (Jaccard's formula), homogenization of clusters, fusion of clusters, construction of table, repetition of relocation and fusion procedure with other options. The threshold value was = 0 and minimum cluster size = 3.

5.2.2 Overall characterization of the whole TABORD result

The 135 selected stream stations and the corresponding 214 species (full TABORD table) gave a table with 18 heterogenous large clusters according to the distribution of species. The most frequent species are found at about 50 % of all the stations: *Cymbella affinis* (48 %), *Achnanthes minutissima* v. *cryptocephala* (55 %), *Synedra ulna* (55 %) and *Tabellaria flocculosa* (58 %). According to the Braun-Blanquet scale (Müller-Dombois & Ellenberg 1974 p. 196) these are classified as having intermediate constancy (= present in 40.1 % – 60 % of all samples). Most of the species are rare, i.e. present in less than 20 % according to the same scale. In this case quantitative scores were applied in order to judge the relative importance of presence-absence versus quantitative data. Many have expressed the view that quantitative measures add appreciably to the ecological information on vegetation (see for example Kassas & El-Abyad 1962–63). The ecological parameters were evaluated from basic data of each station included.

5.2.3 Characterization of the individual TABORD clusters

The clusters (Table 12) are treated below in closest assemblage order.

Cluster 4. The biggest cluster including 39 stations. The four most constant species are involved, namely *Cymbella affinis, Achnanthes minutissima* v. *cryptocephala, Synedra ulna*, and *Tabellaria flocculosa*; several more or less rare species occur. *Rivularia biasolettiana* is the most common species of the rare ones and creates in some cases an intermediate stage to a *R. biasolettiana* type (see below). The most striking feature of this cluster is the high frequency of stations located in biotopes undisturbed by human influence (Fig. 62). Also, calcium-rich waters are not included. In two cases in populated land, the algal community has shifted over to a *R. biasolettiana - Chara* type and the four above-mentioned species do not occur as dominants.

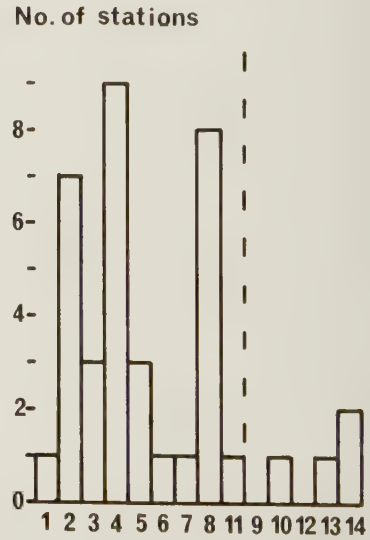


Fig. 62. The surrounding vegetational types of stations included in cluster 4 obtained by TABORD (1–8,11 biotopes undisturbed by human influence, 9–10, 12–14 disturbed biotopes, see text).

Cluster 11. The four most frequent algae (see 5.2.2) and *Bulbochaete* spp. dominate and the last one occurs in largest quantities in the eight stations creating this cluster. The main algal constellation shows many deviations in species composition in the stations included. It prefers streams with clear water, in open, mostly undisturbed forests of all types. There is a change towards a dominance of *Nostoc* spp. at very high values of conductivity, pH, and calcium content. In such cases insolation is lower.

A *Cocconeis-Bulbochaete* type may also occur on a bottom substrate of silt. In alpine birch forest areas there is a shift over to a *Fragilaria-Bulbochaete* type with *F. intermedia* as a dominant with probable preference for such habitats.

Cluster 7. Stream stations with only single individuals of algae. The habitats are characterized by strongly brown-coloured water, or by very low insolation, or a bottom substrate of silt, parameters which together or individually normally provide very sparse vegetation. The available species in these waters were *Synedra ulna* and *Tabellaria flocculosa*.

Cluster 12. Stream stations in rather dark forests with waters of low nutrient content. The dominating algae in these habitats are *Mougeotia e* and *Zygnema b* accompanied by the four above-mentioned frequent algae (see 5.2.2).

Cluster 21. *Zygnema b* accompanied by many rare species in different habitats is the typical dominant in this algal community, otherwise found in all types of light habitats, but growing only on bottoms of stones and boulders.

Cluster 14. Mostly small streams at high altitudes; low conductivity, pH, and calcium contents. Dominant species are *Frustulia rhomboides* v. *saxonica* and *Tabellaria flocculosa*, accompanied by several fairly infrequent species.

Cluster 13. *Stigonema mamillosum* is the dominant alga in habitats characterized by high insolation such as alpine heath, clear-cut areas, etc. Cluster 13 is closely connected with the foregoing but includes algal vegetation, probably avoiding coloured brown waters which vegetation in stations of cluster 14 seems to tolerate. pH mostly around 7, but in cluster 14 down to 5.2 (mean value 5.9).

Cluster 20. As frequently dominant species *Mougeotia d* characterizes these clusters of stations, mostly situated at low altitudes with surroundings of mixed rather dark forests, both in streams with low and high contents of calcium. The cluster shows a great variability in algal vegetation with also dominating algae such as *Synedra ulna* (high conductivity) and *Spirogyra a* (low calcium).

Cluster 18. *Didymosphenia geminata* is dominant, accompanied by *Cymbella affinis, Achnanthes minutissima* v. *cryptocephala*. This type seems to occur preferentially in waters with pH > 7, in populated areas, probably depending on a low nutrient supply, but sufficient to alter the normally oligotrophic waters.

Cluster 9. Three stations dominated by *Chaetophora elegans*; in one, however, codominance by *Chara*.

Cluster 3. The red alga *Batrachospermum moniliforme* dominates this community, mostly found in small dark streams with relatively high values of conductivity, calcium content, and a pH $\geqslant 7$. Accompanying algae are *Achnanthes minutissima* v. *cryptocephala, Synedra ulna*, and *Navicula radiosa*.

Cluster 22. *Oedogonium* sp. 1 and 2 (narrow forms) dominated the algal constellation of the stations, associated by *Achnanthes minutissima* v. *cryptocephala, Fragilaria intermedia*, and *Synedra ulna*.

Cluster 10. Very few algal individuals and species. Compared to Cluster 7, the "dominant" species here is *Achnanthes minutissima* v. *cryptocephala*. In one station the small quantities depend probably on small light quantities and in the other two stations on the silt bottom.

Cluster 8. Stations forming a *Rivularia haematites* community, a real calcium community, only in waters with high calcium content, conductivity, and pH. Mostly in small streams in the lowland area around Lake Storsjön. Accompanying algae were *Synedra ulna, Batrachospermum vagum* or *B. moniliforme*.

Cluster 6. A *Lemanea fluviatilis* community, also a lowland community found in streams with high conductivity, pH, calcium content but subject to low insolation. The *Lemanea* tufts were always found in those parts of the stream station where the current velocity was high. The accompanying alga was another red alga *Batrachospermum moniliforme* f. *helminthoideum*.

Cluster 5. Also a dark biotope type. Stations mainly dominated by *Batrachospermum moniliforme* f. *helminthoideum*. In dark biotopes, in contrast to the foregoing in streams with low values of calcium content, pH, and conductivity, although subject to still lower values of insolation. Associated alga is *Navicula radiosa*.

Cluster 19. The diatom *Achnanthes minutissima* dominated, in one station *Draparnaldia plumosa*, accompanied by *Navicula cryptocephala* and *Gomphonema intricatum*; mostly in streams with high values of pH, conductivity, and calcium but also in very oligotrophic waters.

Cluster 16. Three stations were included. *Diatoma hiemale* f. *turgidula* is the main dominant while *Anomoeoneis brachysira* v. *thermalis* and *Tolypothrix penicillata* occur as codominants. High values of conductivity, pH, and calcium content in all stations.

5.2.4 Comparisons between the five subparts of the whole dataset and the selected part

All clusters in the selected part were recognized in the five subsets. *Zygnema a, Rivularia biasolettiana*, and *Tolypothrix penicillata* did not create their "own" clusters in the selected part but were doing so in the

subparts 1, 3, and 4 respectively on the whole dataset. Another feature from the clusters in the total of five subsets is the presence of more unique clusters than in the selected part where some of them have not been included for natural reasons.

5.2.5 Unique algal communities (= stations)

The TABORD analysis revealed that many stations were unique, e.g. they had their own species combination.

The TABORD analysis run on the five parts which together make up the whole dataset showed that about 12—30 % were unique. From a selected dataset with a minimum cluster size of 1 about 29 % were unique (one-station clusters).

Unique montane communities include, among others, species such as *Didymosphenia geminata* and *Hydrurus foetidus* accompanied by some diatoms, and a *Tolypothrix saviczii* group found together with a constellation of diatoms all preferring low pH, conductivity and calcium content tolerating very high colour values of the water (130 mg Pt/l).

A lowland community was composed of the dominant *Cocconeis placentula* v. *euglypta* with additional species such as *Chantransia* sp., *Asterionella formosa, Cymbella lanceolata, Epithemia argus, Comphonema intricatum, Navicula pupula* v. *rectangularis* and *Synedra ulna*. This station did not diverge with regard to parameters measured; it was in a lowland stream with quite high values of conductivity, pH and calcium content and had a bottom substrate of silt.

Another lowland community found in a stream with very high calcium content (63 mg Ca/l) running through a mire with gravel and stones as bottom substrate, includes species like *Cymbella prostrata, Pinnularia interrupta* and *Surirella linearis*, with *Tolypothrix distorta* v. *penicillata* as dominating. Normally a *Rivularia haematites* community would be expected here.

A special algal community found near Mt. Anaris was on mats of the hepatic *Marsupella aquatica*, where long threads of *Ulothrix zonata* covered the leaves but also cushions of *Stigonema mamillosum* and threads of *Hormidium rivulare* together with some frustules of diatoms.

Another unique algal community was found in the R. Lekarån with very low pH and conductivity. Here there was a dense vegetation of *Melosira* spp. together with *Eunotia tridentula* v. *perminuta, Meridion circulare* v. *constricta, Neidium* cfr *productum, Stauroneis phoenicenteron* and others.

Other unique but by no means special communities exist. In most cases it is difficult to understand why they are unique when the surrounding factors do not seem to be very special. It is possible that most species have a haphazard distribution, and if it is so, how much influence does the dispersion have on selection?

Allen (1971) also penetrates the problem of the complexity of the relationship between the terrestrial and the aquatic situation, considering that the terrestrial nature introduces much more complexity to the system; unlike the more homogeneous aquatic existence, the terrestrial plant is subjected to a constantly and rapidly changing environment which is less pronounced in an aquatic environment. Perhaps this is why distinct parameters cannot be found. Nevertheless the tolerance of many epilithic algae to climates ranging from arctic to tropical may indicate that there are still many gaps in our knowledge of algal ecology.

5.3 A description of the whole dataset with respect to algae included—a very heterogeneous set of data

At the end of the data-processing procedure a new rapid clustering technique became available. The method attempts to provide an idea of floristic similarities and differences between the stations. The clustering program FLEXCLUS (van der Tongeren et al. 1982) was used. With this program it was possible to obtain a clustering of all stations based on all species.

Method

A dataset of 316 species and in this case 448 stations were included. The species occurrences were quantified in accordance with the cover degree scale 1—6 (Chapt. 2.2).

The program FLEXCLUS starts as a single linkage clustering but limits cluster diameters to an arbitrary threshold. From that point the resulting clusters can either be subdivided one by one according to the same strategy, with an automatic threshold

selection, or fused one by one according to the centroid sorting strategy. After each change in the number of clusters a relocation procedure can be performed. Here also SR (= similarity ratio) is used as a measure of similarity.

Result

The first clustering round with a threshold value of 0.4000 resulted in 249 clusters. To obtain a lower number of clusters a new threshold value of 0.3000 was chosen which gave 186 clusters. Most of these clusters contained very few stations; only five included more than 10 and among these one contained 16. As many as 94 stations were unique. Some of these unique stations will be described in Chapter 6 as they are considered to represent communities of their own.

5.4 Ordination of a subset of stations with a Principal Components Analysis

In this case another approach was used to evaluate groups of stations, their algae and parameters. A subset of data was again used here, partly depending on the capacity of the program but also to find out whether a minor dataset is sufficient to visualize the appropriate types.

Method

The ordination of the samples studied was performed by means of a principal components analysis of a matrix of standardized Euclidian distances, following Orlóci (1966): program ORDINA (Roskam 1971). The percentages of explained variance are calculated, and a measure of success, relating the new distances to the original ones is given. The 135 stations with their corresponding 214 species used in the PCA analysis were chosen so as to represent the total variation of the whole dataset.

Analysis of the recorded data

The cluster series from this dataset obtained by means of the classification program TABORD consisted of 135 stations and corresponding 214 species. In Fig. 63 the ordination diagram of these stations is shown according to component scores at the first two

Fig. 63. Ordination diagram of the 135 stations shown according to component scores at the first two dimensions of ORDINA-principal components analysis (the dotted lines divide the diagram roughly in three parts according to text).

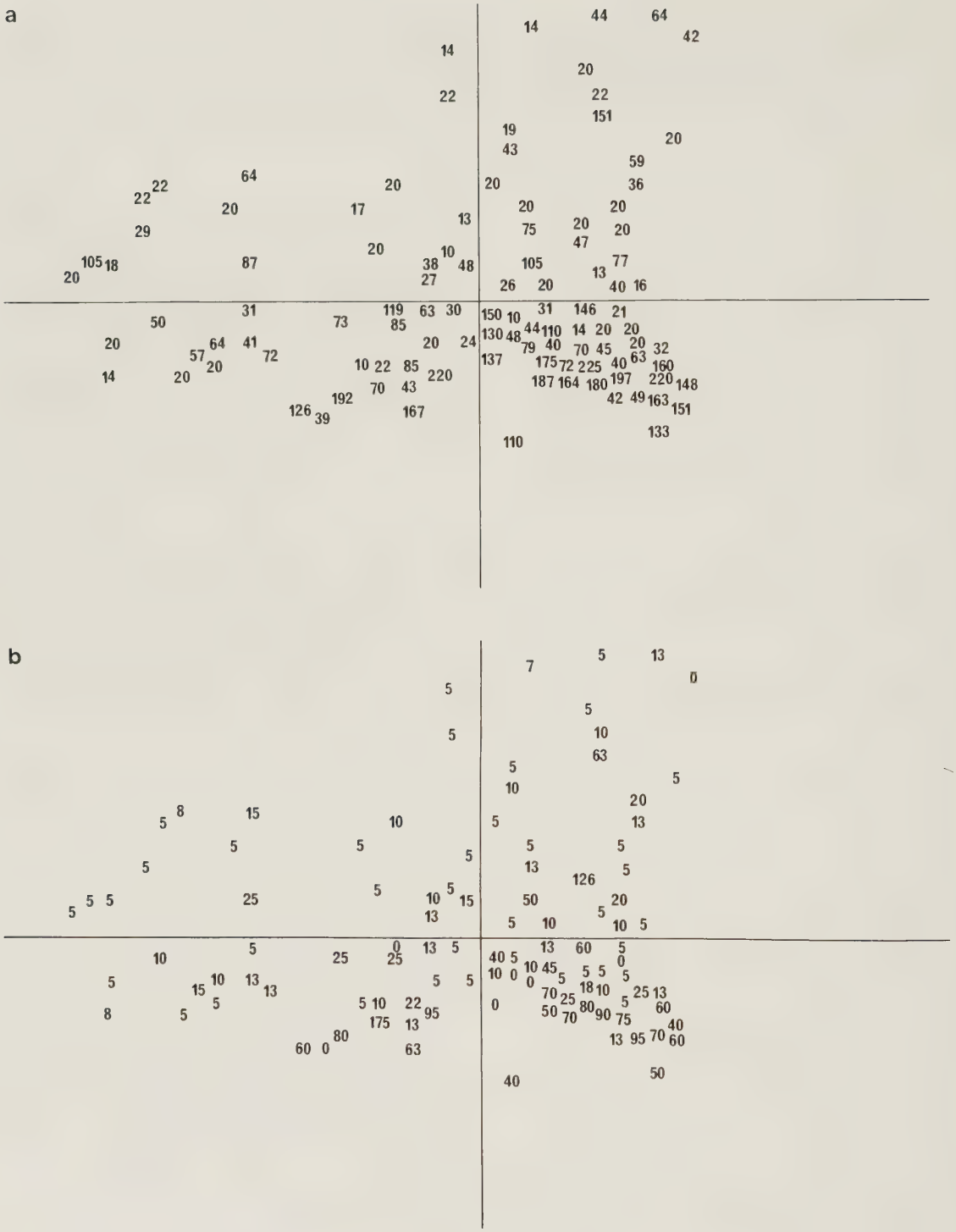


Fig. 64. Ordination of the 135 stations, illustrating five environmental parameters at each station: a) conductivity, b) calcium content, c) pH, d) surrounding vegetation according to scale in Chapt. 2.1, e) insolation.

Fig. 64 c and d.

Fig. 64 e.

dimensions of the ORDINA-principal components analysis. The percentages of extracted variance for the first components are 8.9, 7.3, 5.4, 4.9, 4.5, and 4.0, respectively. Clearly there are no main axes of floristic variation.

The main features (Fig. 63) of the orientation of the stations are a rather high concentration of stations in the low right corner (2nd quadrant) and a more or less equal distribution towards the upper right and left side of the diagram.

Fig. 64 demonstrates how the diagram can be divided roughly into three zones according to conductivity (Fig. 64a), calcium content (Fig. 64b), pH (Fig. 64c), surrounding vegetation (Fig. 64d), and insolation (Fig. 64e). At the low right side we find the stations with the highest values for calcium, conductivity, pH and surrounding vegetation; these are dominated by disturbed habitat type, arable land, pasture land, populated land, etc. The difference between the left hand stations and the upper right stations seems to be more insolation and more extreme oligotrophic waters in the upper right section, while the left part is made up of oligotrophic to very slightly eutrophic streams. According to the dominating algal species, the stations in the left part (Fig. 65a) are built up of species from cluster 4 in the TABORD table, viz. *Achnanthes minutissima* v. *cryptocephala, Cymbella affinis, Tabellaria flocculosa*, and *Synedra ulna*. This community is also characterized by very little human disturbance of the surroundings.

In the other parts of the diagram, clusters are not so clearly discernable. The *Zygnema b* community (cluster 21 in TABORD) together with *Mougeotia e* community (cluster 12) form the outermost stations in the upper-right corner (Fig. 65b and c respectively). One of the differences between these two communities is among others that the *Mougeotia e* community is more frequently found in shaded habitats while the *Zygnema b*, often with *Spirogyra a*, seems to prefer streams with high insolation. These two communities are very close concerning species composition (Table 12).

The lower right part of the diagram contains many communities, e.g. *Rivularia haematites* comm. (cluster 8), *Achnanthes minutissima* comm. *Batrachospermum moniliforme* comm. (cluster 3) and its f. *helminthoi-deum* (cluster 5) comm. All of them are characterized by high conductivity, high calcium content, and are surrounded by pasture land etc. (Fig. 65a, d).

The *Lemanea fluviatilis* comm. appears as rather

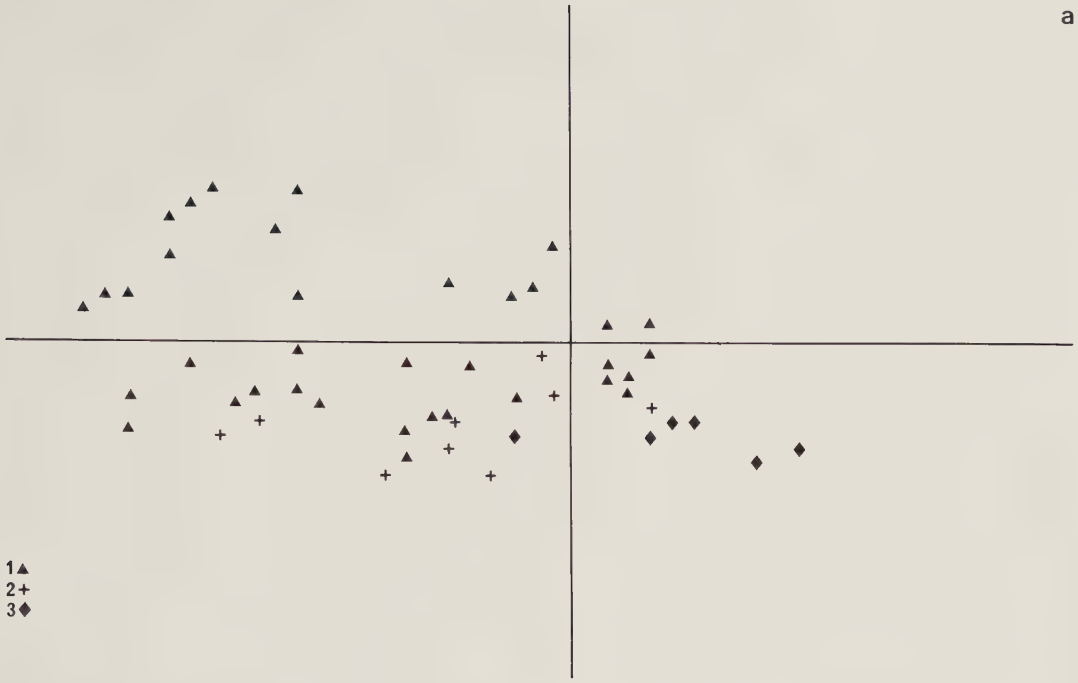


Fig. 65. Ordination diagrams illustrating dominating algal communities and their cluster affiliation (obtained by the TABORD method). a) 1 *Achnanthes-Cymbella* community (Cl. 4), 2. *Didymosphenia* comm. (Cl. 18), 3. *Batrachospermum moniliforme* comm. (Cl. 3)

Fig. 65 b. 1. *Zygnema b* comm. (Cl. 21), 2. *Frustulia* comm. (Cl. 14)

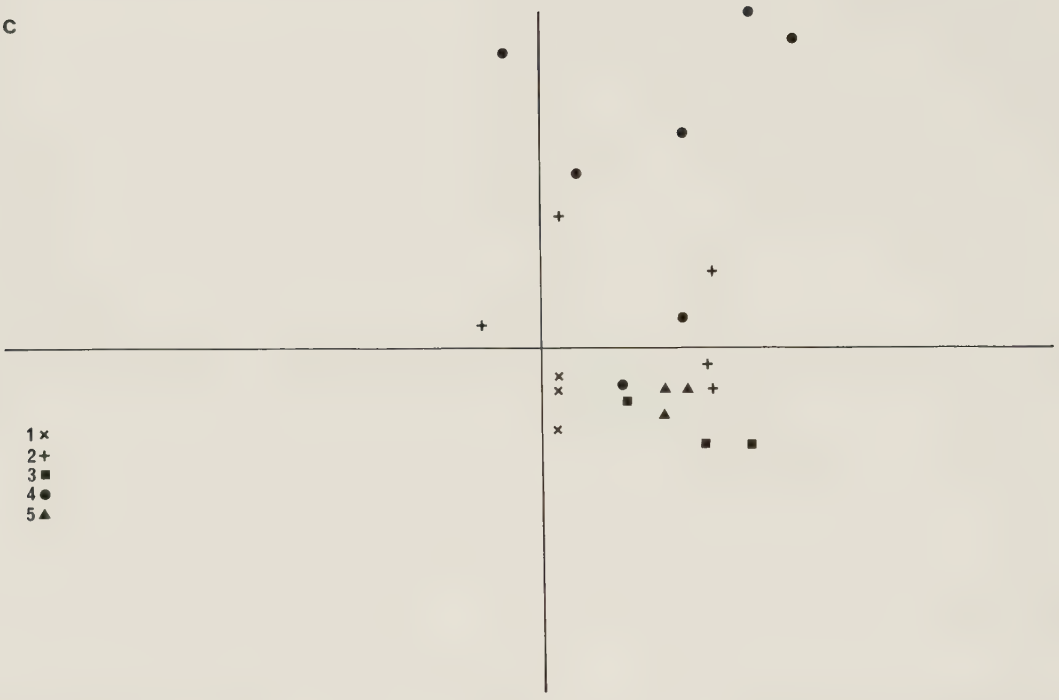


Fig. 65 c. 1. *Chaetophora* comm. (Cl. 9), 2. *Stigonema* comm. (Cl. 13), 3. *Achnanthes minutissima* comm. (Cl. 19), 4. *Mougeotia e* comm. (Cl. 12), 5. very sparse algal vegetation (Cl. 7, 10)

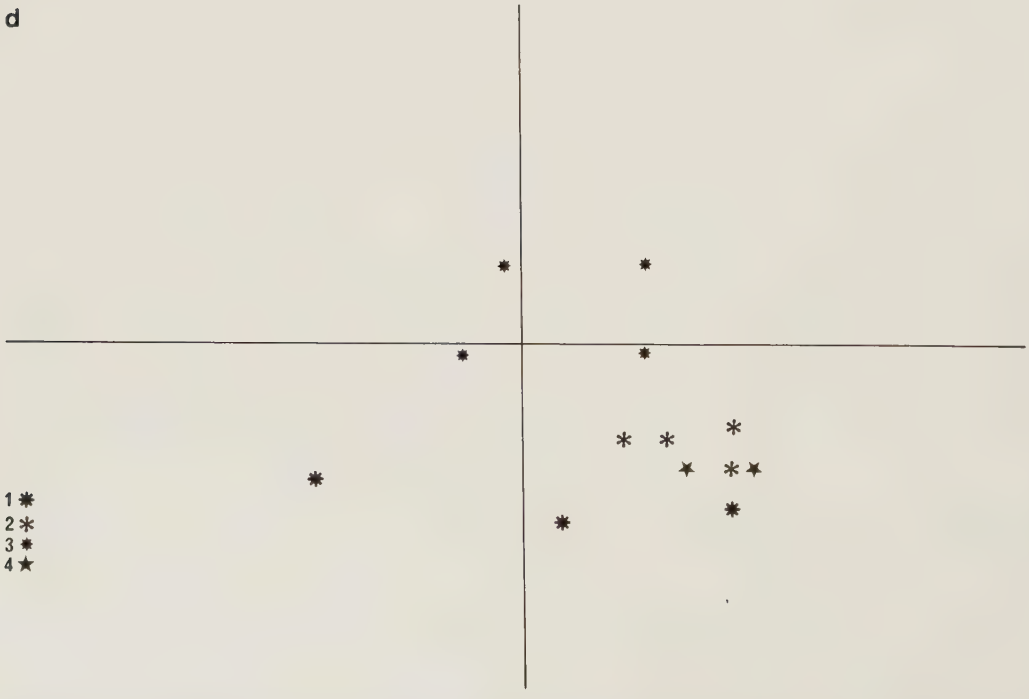


Fig. 65 d. 1. *Lemanea* comm. (Cl. 6), 2. *Rivularia haematites* comm. (Cl. 8), 3. *Oedogonium* comm. (Cl. 22), 4. *Batrachospermum moniliforme* f. *helminthoideum* comm. (Cl. 5)

Fig 65 e. 1. *Mougeotia d* comm. (Cl. 20), 2. *Bulbochaete* comm. (Cl. 11)

spread from the left-hand side part of the diagram to the right, indicating its wide ecological range concerning the trophic circumstances. Nevertheless, it prefers stations with low insolation (Fig. 65d).

The central right part of the diagram (Fig. 65b–e) consists of four well-defined light-demanding communities, characterized by *Stigonema mamillosum* (cluster 13), *Frustulia rhomboides* (cluster 14), *Bulbochaete* spp. (cluster 11), and *Oedogonium* spp. (cluster 22).

Evaluation of the results

The overall characterization of the dataset is its variation along many different independent environmental variables with no major gradients involved. Clearly the attached algal vegetation is very heterogeneous.

There are numerous statements from other countries that the attached algal flora of rivers and rivulets has proved to be rather uniform. On the whole, the *Zygnema* type (Israelson 1949), including all genera of *Zygnemales*, represents a type which does not seem to have been more closely studied outside northern Europe. But there is no reason to believe that this type or either of the other main types found in this study would be restricted to Scandinavia. In fact, literature (Johansson 1982) contains scattered records indicating that it also occurs here and there in other parts of the world. Most of the frequent communities in this study (except *Rivularia haematites*, *Cladophora glomerata*, and *Chaetophora* communities) are mostly found in streams with a low nutrient content.

Discussion

Algologists have neglected multivariate techniques and have consequently been in some danger of overlooking the true complexity of algal biotopes. It seems appropriate that these techniques should be used in a study of freshwater benthic algae.

The algal communities in the Ardennes streams (Symoens 1957) contain many of the species present in Jämtland in common but different species are dominant in the two regions. *Cymbella ventricosa* creates an algal community in the Ardennes while it is never dominant although very frequent in Jämtland, in the present study being present in about one-fifth of the streams. Another community in the Ardennes is *Diatoma hiemale* and *Meridion circulare*, both found in well-aerated streams. In turbulent

streams *Tabellaria flocculosa, Eunotia* and *Pinnularia* are more apparent. In Jämtland streams *Diatoma hiemale* f. *turgidula* forms a community type in running waters, often calcium-rich. Symoens (op. cit.) found the community *Eunotia exigua* and *Pinnularia subcapitata* adapted to turbulent, acid, clean waters. It could be analogous to the *Frustulia* community in Jämtland which, with *Eunotia* species as associated algae, is found in streams characterized by low pH and conductivity and no calcium content, mostly in alpine areas.

The encrusted cyanophyceaes communities in the Ardennes are characterized by *Chantransia incrustans* and *Phormidium incrustatum*, but in Jämtland by *Rivularia haematites*. Another calcium-rich community is the *Vaucheria* community present in both regions together with *Cladophora glomerata*; additional species in Jämtland were also *Cymbella prostrata, Diatoma hiemale* v. *mesodon, Meridion circulare*, and *Nitzschia angustata* v. *acuta*.

The *Draparnaldia glomerata* community was found in Ardennial streams but not frequently. *D. glomerata* dominated in four of the eleven finds in Jämtland and seems to prefer waters low in temperature, pH, conductivity but with rather high insolation. It grew in waters running through many types of vegetation, except glacier areas, alpine heath, pine forest, deciduous forest, and arable land.

McIntire (1973) used a cluster analysis, and a principal component analysis to examine the degree to which the diatom flora of the Yaquina estuary can be partitioned into discrete communities and to relate the composition of the flora to selected physical properties of the estuary. He got results that were consistent with the hypothesis that the distribution of marine and brackish water diatoms along salinity and desiccation gradients in the Yaquina estuary form a continuum rather than a series of discrete, co-adapted communities. A continuum approach seems to be highly applicable on benthic algae in Jämtland.

Coesel (1981) has in 400 different samples distinguished six biotope types, based on characteristic desmid species combinations, but the floristic differences between these clusters from which these ecological types emanate are more of a relative than of an absolute nature showing that only characteristic species combinations can be distinguished. This occurs also in the present study where many species of the stations overlap but also many species are unique for certain stations. The three main clusters in the Dutch broads are the result of substrates and light conditions, parameters which also give distinct clusters in the present study. Here the "light communities" are found both in alpine heaths and in clear-cut areas, while in contrast, "shadow communities" also depend on the nutrient status of the waters.

5.5 Ordination of the whole dataset with reciprocal averaging (RA)

Introduction

Hill (1973) has elucidated the analysis of reciprocal averaging. During the study a new program for RA using a condensed data storage became available (Hill 1979) which now made it possible to include all stations and all species. The advantage of this method is that there is usually no difficulty with the interpretation (Whittaker 1967). Hill called the process "reciprocal averaging" because the species-scores are used to average stand-scores and reciprocally the stand-scores are used to average species-scores. He also discussed the similarities and dissimilarities to principal component analysis. The particular attraction of RA is that it simultaneously ordinates both the species and the stands. An important difference between principal components and reciprocal averaging, is that the stand scores are with principal components the sum of a set of species scores (loadings) for those species which occur in the stand, while with RA an average of a set of species scores is used. This means that principal components analysis, at least in the unstandardized version used in ORDINA is likely to emphasize species-rich stands and to give species-poor ones a rather intermediate position. Another important feature is that much greater importance is given to species of intermediate commoness than to species which are either very rare or very common. Hence, principal components using unstandardized data pay very little attention to rare species; not only do they seldom occur but they will probably have small loadings. Principal components analysis using standardized data, on the other hand, puts the species on a more equal footing.

The following steps are performed (Hill 1973): First the species are weighted by positions along an initial gradient with values between 0 and 100. The

better these positions reflect actual gradient position the more rapid the further calculations will be. With these weights the relevé (here station) scores are calculated and from the relevé totals new species weights are derived. After rescaling so as to make the lowest value again 0 and the highest again 100, these species weights are used to calculate new relevé totals, etc. This iteration leads to a stable set of species and relevé weights, which does not depend on the initial weights. Finally, relevés and species are ordered according to the (rescaled) weights.

Results

The method reveals the rarest species and the corresponding stations at the outermost points on the axes. The eigen values for the four axes were: 0.734, 0.535, 0.492 and 0.446 respectively. From the four axes three types were distinguished and a description of each type is given below.

Type 1: The highest positive scores in relation to axis 1 have species like *Sirodotia suecica, Microspora palustris* v. *minor, Eunotia robusta* v. *tetraodon* and *E. arcus* v. *fallax*. These were mostly found in rather high altitude streams or in habitats with high insolation, low conductivity, low calcium content, and pH < 7. Some streams also had very high values for water colour. In the group of algae, which are negatively correlated in relation to factor 1, *Batrachospermum vagum, Vaucheria* spp., and *Hydrurus foetitus* are all very rare species, which seem to have no environmental factor in common.

Type 2: Algae such as *Gloeocapsa gelatinosa, Eunotia exigua, E. praerupta* v. *inflata*, all very rare, seem to prefer small watercourses with no or very little calcium, low colour content and high insolation, either surrounded by open forests or alpine heath. The negative values on this axis (2) are mostly like those negatively correlated in relation to axis 1. This is also applicable to the group of algae positively correlated in relation to axis 3.

Type 3: These rare algae are *negatively* correlated in relation to axis 3: *Stigonema informe, Ulothrix implexa, Frustulia rhomboides* v. *amphipleuroides, Pinnularia microstauron*. Parameters like very low calcium content, high insolation, small streams, bottoms of stones and boulders, moderate to fast-flowing water, and pH < 7 seem to be relevant. The algae connected with axis 4 are found in Type 1.

Discussion

Since the method puts the rarest species at the extremes, the algal constellations are difficult to relate to other groups found earlier in the study. In contrast, the environmental factors seem to crystallize in the same way as parts of the methods used earlier (PCA, CLUSTER, FA, etc.).

6. Classification and ordination of algae communities

6.1 Towards a classification of streams

Two superposed systems are at once recognized in every watercourse. (1) free floating organisms suspended in the flowing water, (2) communities more stable and more firmly localized in the boundary between the water and the bed, and in the interstices of the substrate (Margalef 1960).

The level which is most useful in the classification of rivers has not yet been reached. In river management too coarse a classification would not be particularly helpful in applying general management principles, while at the other extreme, classes containing very few rivers are of little practical use. Ideally, a classification scheme should embrace all the items. To be useful in practice the characteristic features of the classes should be readily and accurately recognizable and quantified.

Several workers have classified whole rivers on the basis of the nature of various parameters, e.g. source (e.g. Thienemann 1936), calcium concentrations (Ohle 1937), Ca/Mg proportions (Dittmar 1955). Naumann (1932) and others attempted to apply criteria similar to those used for lake classification—degree of productivity or eutrophy. Generally, however, these have not proved as useful in lotic situations (= running waters).

Most workers consider that classification of whole river systems is impossible (Berg 1948; Schmitz 1955; Pennak 1971). The most popular basis for classifying stretches of river systems are the readily observable, but less readily definable, river zones. Many workers have proposed different factors considered responsible for the zonation as criteria for classification, e.g. gradients, substrata, annual temperature profiles. Considering factors contributing to zonation, it is unlikely that any single factor would be a satisfactory criterion for classification of rivers. In order to compare the algal vegetation in different localities the vegetation has, as a rule, been analyzed according to the plant sociological methods of Braun-Blanquet, for example by Fetzmann (1956), Messikommer (1942), and Wasylik (1965). However, some authors prefer the characterization by dominant taxa, see Johansson et al. (1977, p. 128), which is not classificatory in the common sense.

Other classifications of streams and stream-stretches are based on a saproby-system (e.g. Kolkwitz & Marsson 1908, 1909; Liebmann 1951: Šrámek-Hušek 1956; Fjerdingstad 1960, 1964, 1965; Sládeček 1973).

The classification of river zones, besides being intellectually challenging and useful in comparing the results of studies on the ecology of different rivers, is also of practical value in fishery and river management.

With the increasing needs for water conservation, both quantitatively and qualitatively, a system of whole-river classification would be desirable in predicting the likely effects of projected management policies on the ecology of the river such as water abstraction and flow regulation.

Rather numerous papers deal with classification of running waters according to physical and chemical parameters, such as those by Nisbet & Verneaux (1970), Pennak (1971), Estrada (1975), Fabri (1977), Fabri & Leclercq (1977) and Estrada (1978). The latter author made her classification on 100 reservoirs throughout the whole of Spain, and treated it with numerical methods. Her work is of relevance for comparisons with this study and is therefore included here.

However, the aim of this study was to investigate as many stream sections (parts) as possible to get an idea of the variance of algal communities according to types of waters. Pennak's (1971) way of classification of lotic habitats was used in this study when selecting variables to find out the types of stream sections in Jämtland. The idea of treating the whole stream or river as a single ecological entity has long been discarded. From source to outlet any stream consists of a longitudinally intergrading series of habitats with a wide array of ecological conditions, and it is only stream segments, stream sections, or

(preferably) stream habitats which may be properly compared and contrasted from place to place. The differences between parts of a river system are well marked. Unfortunately, an adequate classification system must rely on a large set of chemical, physical and biological criteria. In this study 14 different physical and chemical parameters have been used in connection with a characterization of the attached algal communities.

Since plants make up by far the largest part of the biomass, as well as the essential structure of land and water communities, it is reasonable to base the classification upon the plants, in this case the algae.

6.2 The community concept

According to Barkman (1973) the *synusiae* concept would be most appropriate for communities in this study, which could be defined as the abstract units into which similar societies (in a number of phytocoenoses) are classified.

Aquatic communities offer special problems because the differences in specific environments are less stable than in terrestrial communities. Water has no vertical gradient except for light and temperature. Water currents tend to obliterate horizontal and vertical differences in water chemistry. Finally, floating communities may be driven by wind and currents from one rooting plant community to another. For these reasons the synusial approach has been more widely used here than in terrestrial communities.

However, the synusial concept, mostly used in Sweden by the Uppsala school, has increasingly become abandoned. A more modern approach is now the concept of phytocoenose. In this study the concept of *community*, i.e. neutral concept is used. A community can be a partial community or on the other hand a multilayered one. In this study the dominance of single species has been especially important in the delineation of communities.

6.3 Use of numerical methods

The different multivariate techniques have already been discussed to some extent. The use of so many numerical approaches in one study would seem confusing, but all methods together result in a more complete picture of the dataset, which is indeed very heterogeneous (see previous chapters). The most particular method is reciprocal averaging which separates the rarest stations, in this case being those including the rarest species.

For the present work multivariate techniques have been very useful because they provided insights into the data structure that otherwise would probably not have been obtained. While the mathematics involved may be complicated, the methods are conceptually appealing to intuitive common sense.

The ordination methods discussed differ in assumptions and in the aims they are supposed to achieve. Among these methods factor analysis and discriminant analysis are burdened by several restrictive assumptions, e.g. normality. Component analysis has mainly been used as a descriptive model without regard to statistical considerations. It has been useful in handling continuous linear variability in phytosociological samples. The TABORD analysis is an outcome to combine the theoretical and technical advantages of selected numerical methods with a conceptual framework and the common sense of the Braun-Blanquet approach. The table produced gives a diagonal structure of the clusters which were easily evaluated.

6.4 The main algal communities—comparisons between different multivariate analyses

The different community types (Table 13) crystallized from the methods in the foregoing chapters will now be summarized in main communities and their deviations into subcommunities, the latter depending on small variations in environmental factors.

The *main algal communities* with the most common species and their ecological characteristics are as follows:

A community characterized by high altitude, low pH, conductivity, and calcium content; occurring in small streams; with species such as *Zygnema a, Frustulia* spp., *Eunotia* spp., *Stigonema mamillosum*. Species only (or with a few exceptions) found in high altitude streams were *Anomoeoneis zellensis* v. *linearis* and *Tolypothrix saviczii*. All the techniques separated this community although with some minor differences concerning species and parameters (FA, TABORD, CLUSTER, "Kolmogorov", ORDINA). The community is very similar to a high insolation-

Table 13. The main algal communities given by the numerical methods used, their characteristic surrounding factors, habitat preference and indicator species.

A. The algal communities found in alpine streams and/or streams with high insolation

	Anomoeoneis-Tolypothrix community	Stigonema mamillosum community	Bulbochaete community
Factors:	high altitude low pH low conductivity low calcium content small streams	see the Anomoeoneis--Tolypothrix community	high insolation strong current velocity low values of conductivity pH around 6 low calcium content
Habitats:	high altitude streams	alpine streams	alpine heath alpine birch forest clear cut area light mixed forests mire
Indicators:	Anomoeoneis zellensis v. linearis Tolypothrix saviczii Frustulia rhomboides v. saxonica	Stigonema mamillosum Anomoeoneis brachysira Ceratoneis arcus v. linearis Cymbella gracilis Eunotia lunaris E. pectinalis E. pectinalis v. minor Frustulia rhomboides F. rhomboides v. saxonica F. rhomboides v. capitata Tabellaria flocculosa	Oedogonium spp. Bulbochate spp. Anomoeoneis brachysira v. saxonica Tetraspora gelatinosa Stigonema mamillosum Frustulia rhomboides v. saxonica Anomoeoneis brachysira Tabellaria flocculosa Mougeotia b

B. The algal communities found in calcium-rich streams.

	Rivularia haematites community	Nostoc community	Vaucheria-, Lemanea-, or Mougeotia community
Factors:	low altitude high pH high conductivity high calcium content	slight current velocity high conductivity high calcium content	high calcium content high conductivity small streams cold water
Habitats:	no specific	lowland spruce forest	no specific
Indicators:	Rivularia haematites Cladophora glomerata Vaucheria spp. Amphipleura pellucida Cocconeis placentula v. euglypta Diatoma hiemale f. turgidula Gomphonema intricatum v. pumila Meridion circulare Navicula cryptocephala N. cryptocephala v. veneta Synedra ulna	Nostoc spp. Oscillatoria tenuis Amphipleura pellucida Cocconeis placentula v. euglypta Navicula cryptocephala N. radiosa	Vaucheria spp. Chantransia sp. Cymbella prostrata Diatoma hiemale v. mesodon Meridion circulare Nitzschia angustata v. acuta Lemanea fluviatilis Batrachospermum moniliforme f. helm. Mougeotia d Spirogyra a Zygnema a

C. The algal community found in cold streams.

	Diatoma hiemale community
Factors:	low temperature small streams
Habitats:	no special
Indicators:	Batrachospermum moniliforme Vaucheria spp. Ceratoneis arcus v. linearis Diatoma hiemale v. mesodon Meridion circulare Pinnularia interrupta

Table 13 (contin.)

D. The algal communities found in large and warm streams.

	Stigonema - Bulbochaete community	Rivularia biasolettiana community
Factors:	large and deep streams high insolation	large streams high temperature low altitude slight current velocity low values of colour
Habitat:	no specific	no specific
Indicators:	Stigonema mamillosum Oedogonium spp. Bulbochaete spp. Zygnema b Mougeotia e Spirogyra a and c Cyclotella comta C. kützingiana C. kützingiana v. planetophora Anomoeoneis brachysira A. brachysira v. thermalis Cymbella microcephala Epithemia argus Fragilaria construens Tabellaria fenestrata T. flocculosa	Rivularia biasolettiana Cymbella delicatula Stauroneis phoenicenteron Cymbella cesatii + many of the indicators listed for the Stigonema - Bulbochaete community.

E. The algal communities found in streams surrounded by different types of forests.

	Zygnema a community	Tetraspora gelatinosa community	Microspora palustris v. minor community
Factors:	moderate to strong current velocity bottom of boulders and stones		low calcium content bottom of boulders and stones high values of colour
Habitat:	different forests	deciduous forest	pine forest
Indicators:	Zygnema a Zygnema c Bulbochaete spp. Oedogonium spp.	Tetraspora gelatinosa Gomphonema constrictum v. capitata Cocconeis placentula Synedra rumpens	Microspora palustris v. minor Gomphonema angustatum

F. The algal community found in streams unaffected by human activity.

	Achnanthes - Cymbella community
Factors:	no distinct
Habitat:	most undisturbed biotopes
Indicators:	Achnanthes minutissima v. cryptocephala Cymbella affinis Synedra ulna Cymbella ventricosa Ceratoneis arcus v. linearis C. arcus Tabellaria flocculosa Zygnema b Gomphonema acuminatum v. brebissonii Synedra ulna

G. Three algal communities with special features falling outside the above classification.

	Navicula amphibola community	Didymosphenia community	Very few specimens of algae
Factors:	silt bottom high values of colour	pH $\geq$ 7	very high values of colour very low insolation silt bottom
Habitat:	mire	no specific	no specific
Indicators:	Navicula amphibola N. pupula Amphora ovalis Oscillatoria tenuis Microspora palustris v. minor	Didymoshenia geminata Cymbella affinis Achnanthes minutissima v. cryptocephala	Few specimens of: Tabellaria flocculosa Synedra ulna

community in the lowland with the exception of some "alpine" species (Table 13, Type A).

A community characterized by its presence in streams at low altitudes, running through arable land, and by high values of calcium and conductivity, mostly pH >7. Very frequently dominant species in all these streams were *Rivularia haematites, Batrachospermum moniliforme* (sometimes lime-encrusted), *Amphipleura pellucida, Gomphonema intricatum*. Most of the techniques separated this type of community (FA, TABORD, "Kolmogorov", ORDINA). The subcommunities are shown in Table 13, Type B.

A community in large, warm streams in open biotopes, with rather low values of conductivity; with species like *Stigonema mamillosum, Oedogonium* spp., *Bulbochaete* spp., *Cyclotella* spp., *Anomoeoneis* spp., *Tabellaria* spp. Found in several analyses (FA, TABORD, "Kolmogorov", ORDINA). Two types were recognized, see Table 13, Type D.

A community in small and cold streams frequently in dark habitats; characterized by species such as *Diatoma hiemale* v. *mesodon, Ceratoneis arcus* v. *linearis, Meridion circulare*, and *Pinnularia interrupta*. In three types of analysis (TABORD, FA, Kolmogorov) (Table 13, Type C).

A community in undisturbed streams, in streams surrounded by all types of biotopes but not in clear-cut areas, pasture land etc. Very few finds were made in populated land. Dominating algae are such as *Achnanthes minutissima* v. *cryptocephala, Cymbella affinis, Synedra ulna, Cymbella ventricosa, Ceratoneis arcus* and its variety *linearis, Gomphonema acuminatum* v. *brebissonii*. In three types of analysis (FA, CLUSTER, TABORD) (Table 13, Type F).

The streams with no or very few algae characterized by heavy brown coloured water, very little or no insolation, silt or alpine slate bottom. Only in the TABORD analysis (Table 13, Type G).

Three communities only found in one or two of the types of analysis but frequent in nature:

A community dominated by *Didymosphenia geminata*, a well-known algal species often causing problems in rivers where it occurs in mass production, found together with *Cymbella affinis* and *Achnanthes minutissima* v. *cryptocephala*. The surroundings are often populated land and pH in most cases 7 or above (TABORD) (Table 13, Type G).

Communities in streams running through different types of forests. In streams with moderate to high current velocity, with boulders and stones. The less well-defined but frequent species such as *Zygnema a* and *b, Bulbochaete* spp. and *Oedogonium* spp. were found. Another algal constellation, more frequently found in streams through deciduous forests is characterized by *Tetraspora gelatinosa, Gomphonema constrictum* v. *capitata*, and *Synedra rumpens*. Streams through spruce forests *Achnanthes minutissima* v. *cryptocephala, Cymbella affinis*, and *Synedra ulna* as dominants. These communities were distinguished in the analysis of FA and ORDINA (Table 13, Type E).

A community in streams running through mires was dominated by species such as *Navicula amphibola, N. pupula, Amphora ovalis, Oscillatoria tenuis, Microspora palustris* v. *minor*. These streams frequently had silt bottoms and high values for water colour (FA) (Table 13, Type G).

Discussion

To compare the communities distinguished in this study with results from other investigations several papers of a descriptive character from many parts of the world were consulted. Many species and communities discussed here are also found elsewhere. The most appropriate summaries for nordic waters have been given by Israelson (1949), who classified running waters according to attached algae in the famous *Zygnema* and *Vaucheria* streams, and Kawecka (1980) who attributed ecological characters to communities of sessile algae present in European mountain streams (including one in the Kebnekaise Mts. of northern Sweden).

Papers dealing with both attached algae and some sort of numerical approach have been mentioned in the present Chapter 6.4. The various approaches have also been partly discussed in foregoing chapters in connection with the different numerical techniques used.

In the early seventies papers dealing with multivariate techniques began to appear more frequently. Allen (1971) dealt with algae on terrestrial rock surfaces, including 74 sites and 105 species, using a principal component analysis. Most communities consisted primarily of one or a few dominant species, a large number of other species forming quantitatively very small parts of the vegetation. He concluded, therefore, that only a very limited understanding of the whole vegetation in his investigation area could be obtained if the dominant species was allowed to overshadow the lesser species. Rare species are often presumed to be at the limits of their ecological range and are, therefore, good indicators of limiting environmental parameters. This is also true for Jämtland, but in the characterization of the algal communities the dominant species have been retained since they provide a clue to the environmental interpretation of the stream in observation in the field. Nevertheless, despite very similar environmental fac-

tors, the accompanying rare respectively common species are different in Allen's and the present studies (cf. Table 13).

Some environmental parameters, seem to exert their influence on algal vegetation over wide areas. According to Allen (1971) these factors are rock type, pH, and the source of the water running over the rock, while additional parameters operate at each site and seem to influence the vegetation of particular sites independently of the particular floristic region. Examples of the latter are angle of the rock, light and water quantity, but not quality. The paramount environmental parameters in the present study in Jämtland are the occurrence of bedrock, vegetation and altitude whereas small-scale parameters involve water conditions in and around the watercourse, pH, conductivity, substrate and light.

Later, McIntire (1973) elaborated a system of diatom associations in the Yaquina estuary, Oregon, using cluster- and principal component analysis. He emphasized that cluster analysis only serves to indicate the groups of taxa that tend to co-occur by inference and have similar ecological preferences. He also stated—in close agreement with results of the present study—that although taxa within a cluster have more similar distributions than taxa from different clusters, there is still a considerable variation in the distributions of taxa within a species cluster. This is also the case with many groups in the Jämtland streams a result obtained by the numerical methods.

Descy (1976) used a principal component analysis including both physico-chemical factors and algae to separate pollution tolerant diatom species aggregating in one part of the diagram from non-tolerant species in the other part. The non-tolerant species could to some extent be identified with species occurring in the communities found in the left part of the ORDINA-diagram presented here and the more tolerant species in the lower right part (Fig. 65).

Leclercq (1977) treated data on diatoms and relevant parameters collected throughout one year with a factor analysis and found two distinct algal communities, e.g., *Eunotia exigua* and *Pinnularia subcapitata* in an acid stream with rather low conductivity, and *Diatoma hiemale* and *Meridion circulare* in a stream with pH up to 7 and slightly higher conductivity (around 80 μS) and calcium values. In Jämtland acid streams were not frequent but *Eunotia* species dominated in those streams with pH between 5 and 6. *Meridion circulare* was found in slow-flowing streams with high values of pH, conductivity and calcium (Chapt. 3.2.2), while *Diatoma hiemale* preferred streams with low calcium content but otherwise as the ref. curve.

Some of the papers dealt with below do not include attached algae but are interesting because of the technique used and the general conclusions reached. Lewandowsky (1972) studied phytoplankton populations in ponds of varying salinity and temperature and found that most of the forms observed in these irregularly varying habitats were, not surprisingly, flexible, "opportunistic" species, forming dense paucispecific blooms composed mainly of a few dominant species. In some habitats the dominant species are almost always present but can be used to differentiate samples only if consideration is paid to their differences in abundance. As to Jämtland, these statements are applicable to several diatoms which are available in many streams and mass develop in some, such as *Achnanthes minutissima* v. *cryptocephala, Ceratoneis arcus* v. *linearis, Synedra ulna* and *Tabellaria flocculosa*.

Allen & Koonce (1973) studied phytoplankton in Lake Wingra and treated the data with principal components ordinations. One of their conclusions of interest for the present study is that phytoplankton data (as compared to terrestrial vegetation data) do show weak correlations while, in general, the number of specimens of any one species in any sample is large enough to be statistically robust. The weakness of the correlations between species has biological significance, and it is believed that this relates to the homogeneous nature of the aquatic environment. They also stated that the opportunistic species with narrow ecological ranges have something in common with weeds among terrestrial plants, and weeds gave rise to crops. The species that contribute to the food chain are those we should encourage; they are the opportunists and should be further investigated.

Allen & Skagen (1973), working with multivariate geometry as an approach to algal community analysis, concluded that numerical classification as a tool in algal ecology has many applications. The *intuitive* classification of lakes and streams (the author's comm.) has been the usual approach and thus objective multivariate classificaitons will surely be of assistance. Subjective approaches are always in danger of artificially reinforcing themselves by developing schools of thought, so a fresh approach

Table 14. Indicator species, where non-diatom taxa are referred to in systematic order according to Bourrelly 1966, 1968 and 1970 and diatoms in alphabetic order. Figures in brackets refer to number of measurements of each factor. * refers to figures in Tables 1-4 in Johansson (1982, in prep.)

	altitude (m a.s.l.)	size of stream	temp. (°C)	pH	cond. (uS)	calcium content	insolation (%)	colour (mg Pt/l)	surrounding vegetation*	current velocity*
CHLOROPHYTA										
Tetraspora gelatinosa								<30(10)		
Ulothrix zonata					< 80(11)					
Chaetophora elegans	<700(16)						<60(20)			
Cladophora glomerata	<400(6)									
Zygnema a									alpine heath	
Zygnema b										high
Zygnema c	<700(8)							<50(8)		
Spirogyra a					<140(31)					
Spirogyra b	<500(11)		> 8(12)	>6.7(11)						
Spirogyra c	<400(7)									
CHROMOPHYTA										
Centrales										
Cyclotella comta	<600(11)			>6.9(13)						
C. kützingiana	<500(11)			6.6-7.7(11)				<30(11)		
C. kützingiana v.planetophora	<400(8)				< 80(7)			<30(8)		
Pennales										
Achnanthes lanceolata	<800(10)							<30(10)		
A. minutissima										low
Anomoeoneis brachysira					< 80(28)	<20(26)				
A. exilis				6.5-8.0(23)	<160(23)					
A. zellensis v. linearis							>50(11)		alpine heath	
Ceratoneis arcus										high
C. arcus v. linearis										high
Cocconeis placentula v.euglypta	<650(60)									
Cymbella aequalis			> 8(12)					<30(12)		
C. cistula			>10(10)							
C. delicatula			> 8(14)							
C. gracilis		small		<7.3(6)	<120(6)					
C. naviculiformis								<30(8)		
Diatoma hiemale v. mesodon			<12(26)							
D. hiemale f. turgidula				6.6-7.9(33)						
Didymosphenia geminata				6.6-8.0(32)						
Epithemia argus	<400(8)	big (8)		6.6-7.7(9)						
Eunotia arcus				<7.7(20)						
E. lunaris			> 7(13)	<6.5(6)					alpine heath	
E. pectinalis				<7.5(36)						
E. praerupta						<15(12)				
Fragilaria capucina										high
F. construens					<100(13)					
F. construens v. venter				>7.0(7)						
Frustulia rhomboides				<7.5(7)	<100(7)	<30(12)				
F. rhomboides v. capitata				< 7(14)	< 60(14)	<13(13)			alpine heath	
F. rhomboides v. saxonica					<100(33)					
Gomphonema acuminatum v. coronata				6.0-7.6(15)	<120(15)	<35(14)				
G. constrictum v.capitata					< 80(7)	<15(7)				
G. intricatum v. pumila	<600(11)		> 9(11)	6.7-8.0(10)						
G. longiceps v. subclavata f. gracilis			10-15(8)							
Meridion circulare	<700(13)			6.6-8.0(14)						
Navicula bacillum				7.2-7.7(9)				<40(16)		
N. cryptocephala v. veneta	<600(18)			>6.6(15)						
N. gracilis			6-14(16)	>6.9(12)						
Pinnularia gibba				<7.2(10)						
Synedra acus							>40(11)			
S. rumpens	<600(10)				<80(8)					
RHODOPHYTA										
Batrachospermum moniliforme	<600(30)	small (34)								
B. moniliforme f.helminthoideum	<500(15)	small (15)		>6.5(15)						
Lemanea fluviatilis	<600(12)	small (12)			<160(12)					
CYANOPHYTA										
Stigonema mamillosum					< 40(26)	<12(25)				high
Tolypothrix saviczii				>7.5(6)	< 60(6)	<10(6)	>60(14)			
Rivularia haematites	<450(22)			>7.1(21)	> 80(21)	>35(20)				

will either serve as a comforting reassurance or will point out weaknesses in the classical criteria.

Wiegleb (1981) used the 39 most frequent water plant species from 154 sections of watercourses in Southern Germany in a multiple discriminant analysis on the analysis of the correlation between macrophyte vegetation and water quality. He found that simple indices, e.g. diversity indices, are totally useless and that the species has to be in the centre of interest because only in this way can all indicator values be taken into account. Generalization of the research results which might be valid in different water types and geographical areas—at least in Central Europe—is still distant. The multivariate approach seems to be the only way to synthesize the information which is now scattered in different publications.

6.5 Indicator species

In this chapter indicator species are used in the sense that they show environmental characteristics, e.g. one alga may indicate that the biotope is rich in calcium, while another indicates a low pH, etc.

Special attention will be paid to frequent and dominant species, since their ecological preferences can be checked statistically, whereas rare species are generally supposed to be at their outermost limits of distribution. On the other hand, in terrestrial biotopes fairly rare species are sometimes the most interesting, since they may differentiate two communities from each other, often depending on some change in the environment. This does not seem to be so adequate in aquatic communities.

The presence of certain groups of species may often provide a much more effective indication of environmental factors than single dominant or abundant species, because they often reflect disturbance (Westhoff & van der Maarel 1973).

Most algal species have been found within a wide range for most environmental factors but with preferences in certain intervals (Table 14). Here the only indicator species that will be presented are those which seem to have comparatively narrow ecological ranges. It should be borne in mind that the absence of a species may depend not only on ecological factors but also on it being overlooked in the microscopical analysis.

Many attached algae have different ecological preferences in different biotopes depending on whether they are in their optimal area or in the periphery. Therefore, it is necessary when applying ecological characteristics on species and species groups, to rely on the frequency and dominance of the species concerned.

CONCLUDING REMARKS

A general approach in all multivariate techniques applied to obtain ordered structures along ecological gradients has been the use of axis-reducing and class-dividing tools where the basic mechanism for joining or separating structures has been some sort of similarity or dissimilarity matrix.

The algal communities have been shown capable of being categorized to some extent but much variation and heterogeneity remains to be interpreted. A possible future approach might be to consider various combinations of positive and negative biological interactions of a progressively higher order. No advanced methods are available to appropriately deal with the kind of ranked presence/absence data material as presented in this study. Hopefully the construction of an algorithm, where the reduction is not in number of principal components etc., but in retaining an increasing order of significantly interacting species combinations, would be a biologically meaningful approach where, as in the case of aquatic communities, the apparent heterogeneity of the community structure is substantial.

7. List of species

Below follows the list of taxa found in Jämtland during the investigations of 1975–76. The complete ecological descriptions made in this study on all species are found in Johansson (1982) while a selected smaller part is treated in Chapt. 3.2.2. The arrangement of the taxa follows Bourrelly (1966, 1968, 1970) with head divisions after the systematics of Bourrelly (1970 p. 466). The taxa of Pennatophycidae are arranged in alphabetic order.

CYANOPHYTA

Gloeocapsa gelatinosa Kütz.
(Syn. *G. punctata* Näg.)
G. montana Kütz.
Chroococcus turgidus (Kütz.) Näg.
(Syn. *Gloeocapsa turgida* (Kütz.) Hollerbach)
Stigonema mamillosum (Lyngb.) Ag.
S. informe Kütz.
S. ocellatum (Dillw.) Thuret
Tolypothrix distorta (Fl. Dan.) Kütz.
T. distorta f. *penicillata* (Ag.) Koss.
T. saviczii Koss.
Scytonema tolypothrichoides Kütz.
S. mirabile (Dillw.) Born.
S. myochrous (Dillw.) Born.
Calothrix baueriana (Grun.) Hansg.
C. gypsophila (Kütz.) Thuret
Rivularia biasolettiana Menegh.
R. haematites (D.C.) Ag.
R. sp. (spp.?)
Nostoc spp.
Oscillatoria amphibia Ag.
O. irrigua (Kütz.) Gom.
O. pseudogeminata G. Schmidt
O. rupicola Hansg.
O. splendida Grev.
O. tenuis Ag.
O. spp.
Lyngbya martensiana Menegh.
L. spp.
Phormidium ambiguum Gom.
P. autumnale (Ag.) Gom.
P. valderiae (Delp.) Geitl.
P. spp.

RHODOPHYTA

Batrachospermum boryanum Sirod.
B. moniliforme Roth
B. moniliforme f. *pyramidale* (Sirod.) Israels.
B. vagum (Roth) Ag.
Sirodotia suecica Kylin
Lemanea fluviatilis (L.) Ag.

CHLOROPHYTA

Tetraspora gelatinosa (Wahlenb.) Ag.
T. cylindrica (Wahlenb.) Ag.
Schizoclamys gelatinosa A. Br.
Ulothrix zonata (Web. et Mohr) Kütz.
Ulothrix spp.
Hormidium rivulare Kütz.
Stichococcus minor Näg.
Microspora amoena (Kütz.) Rab.
M. palustris v. *minor* Wichm.
Stigeoclonium spp.
Chaetophora elegans (Roth) Ag.
Draparnaldia glomerata (Vauch.) Ag.
Chaetonema irregulare Nowakowski
Oedogonium spp.
Bulbochaete spp.
Cladophora glomerata (L.) Kütz.
Zygnema a (Israelson 1949)
Z. b "
Z. c "
Mougeotia a (Israelson 1949)
M. b "
M. c "
M. d "
M. e "
Spirogyra a (Israelson 1949)
S. b "
S. c "
S. d "
Chara spp.

CHROMOPHYTA

CHRYSOPHYCEAE
Hydrurus foetidus (Vill) Trèv.

PHAEOPHYCEAE
Heribaudiella fluviatilis (Aresch.) Sved.

XANTHOPHYCEAE
Vaucheria spp.

BACILLARIOPHYCEAE
Centrophycidae
Melosira granulata v. *angustissima* O. Müll.
M. italica v. *subarctica* O. Müll.
Cyclotella comta (Ehr.) Kütz.
C. kützingiana Thwaites v. *kützingiana*
C. kützingiana v. *planetophora* Fricke
C. kützingiana v. *radiosa* Fricke

Pennatophycidae
Achnanthes delicatula (Kütz.) Grun.
A. fragilarioides Peters.
A. kryophila Peters.
A. lanceolata Bréb. v. *elliptica* Cleve
A. lanceolata Bréb. v. *lanceolata*
A. lanceolata v. *rostrata* Hust.
A. lapponica v. *fennica* Cleve
A. lapponica Hust. v. *lapponica*
A. linearis W. Smith v. *linearis*
A. linearis v. *pusilla* Grun.
A. minutissima Kütz. v. *minutissima*
A. minutissima v. *cryptocephala* Grun.
A. montana Krasske
A. peragallii Brun et Herib.
Amphipleura pellucida Kütz.
Amphora ovalis Kütz.
Anomoeoneis brachysira (Bréb.) Grun.
(Syn. *A. serians* v. *brachysira* (Bréb.) Cleve)
A. brachysira v. *lanceolata* (A. Mayer) Cleve

(Syn. *A. exilis* f. *lanceolata* Mayer)
A. brachysira v. *thermalis* (Grun.) Cleve
(Syn. *A. serians* v. *brachysira* f. *thermalis* (Grun.) Hust.)
A. exilis (Kütz.) Cleve
A. intermedia Östrup
A. zellensis (Grun.) Cleve v. *zellensis*
A. zellensis v. *linearis* Hust.
Asterionella formosa Hassal
Ceratoneis arcus (Ehr.) Kütz. v. *arcus*
C. arcus v. *amphioxyx* (Rab.) Grun.
C. arcus v. *linearis* Holmboe
Cocconeis diminuta Pant.
C. placentula v. *euglypta* (Ehr.) Grun.
C. placentula Ehr. v. *placentula*
Cymatopleura solea (Bréb.) W. Smith
Cymbella aequalis W. Smith
C. affinis Kütz.
C. alpina Grun.
C. angustata (W. Smith) Cleve
C. aspera (Ehr.) Cleve
C. cesatii (Rab.) Grun.
C. cistula (Hemprich) Kirchn.
C. cymbiformis Ag.
C. delicatula Kütz.
C. helvetica Kütz.
C. lanceolata (Ag.) Ag.
C. lunata W. Smith
C. microcephala Grun.
C. naviculiformis Auersw.
C. parva (W. Smith) Wolle
C. prostrata (Berk.) Grun.
C. rigida Cleve
C. sphaerophora A. Cl.
C. turgidula Grun.
C. ventricosa Ag.
Denticula tenuis Kütz.
D. tenuis v. *crassula* (Näg.) Hust.
Diatoma elongatum (Lyngb.) Ag.
D. hiemale (Lyngb.) Heib. v. *hiemale*
D. hiemale v. *mesodon* (Kütz.) Grun.
D. hiemale v. *genuinum* f. *turgidula* (Kütz.) A. Cl.
D. vulgare Bory
Didymosphenia geminata (Lyngb.) M. Schmidt
Epithemia argus (Ehr.) Kütz.
E. turgida (Ehr.) Kütz.
Eucocconeis flexella (Kütz.) Cleve
(Syn. *Achnanthes flexella* (Kütz.) Brun.)
Eunotia alpina (Näg.) Hust.
(Syn. *E. naegelli* Migula)
E. arcus Ehr. v. *arcus*
E. arcus v. *bidens* Grun.
E. arcus v. *fallax* Hust.
E. exigua (Bréb.) Rab.
E. flexuosa (Bréb.) Kütz.
E. lunaris (Ehr.) Bréb.
E. paludosa Grun.
(Syn. *E. exigua* (Bréb.) Rab.)
E. pectinalis (Dillw.?; Kütz.) Rab. v. *pectinalis*
E. pectinalis v. *minor* (Kütz.) Rab.
E. pectinalis v. *minor* f. *impressa* (Ehr.) Hust.
E. polydentula (Brun.) Hust.
(Syn. *E. tridentula* Ehr.)
E. praerupta v. *bidens* (Ehr.; W. Smith) Grun.
E. praerupta Ehr. v. *praerupta*
E. praerupta v. *inflata* Grun.
E. robusta v. *tetraodon* (Ehr.) Ralfs
(Syn. *E. serra* v. *tetraodon* (Ehr.) Ralfs)
E. sarekensis A. Cl.
E. sudetica v. *bidens* Hust.
E. sudetica v. *crassa* (O. Müll.) Å. Berg
E. sudetica v. *incisa* (Greg.) Mang.
E. perminuta (Grun.) Patr.
(Syn. *E. tridentula* Ehr.)
E. tenella (Grun.) Hust.
E. valida Hust.
Fragilaria capucina Desm. v. *capucina*
F. capucina v. *lanceolata* Grun.
F. construens v. *bionodis* (Ehr.) Grun.
F. construens (Ehr.) Grun. v. *construens*
F. construens v. *venter* (Ehr.) Grun.
F. crotonensis Kitton
F. leptostauron v. *dubia* (Grun.) Hust.
F. pinnata Ehr.
F. pinnata v. *genuina* f. *subrotunda* A. Mayer
F. vaucheria (Kütz.) Peters.
Frustulia rhomboides (Ehr.) De toni v. *rhomboides*
F. rhomboides v. *amphipleuroides* (Grun.) De Toni
F. rhomboides v. *capitata* (A. Mayer) Patr.
F. rhomboides v. *saxonica* (Rab.) De Toni
F. vulgaris (Thwait.) De Toni
Gomphonema acuminatum Ehr. v. *acuminatum*
G. acuminatum v. *brebissonii* (Kütz.) Grun.
G. acuminatum v. *coronatum* (Ehr.) W. Smith
G. angustatum (Kütz.) Rab. v. *angustatum*
G. angustatum v. *productum* Grun.
G. bohemicum Reichelt & Fricke
G. constrictum Ehr. v. *constrictum*
G. constrictum v. *capitata* (Ehr.) Grun.
G. helveticum Brun.
G. intricatum Kütz. v. *intricatum*
Gomphonema intricatum v. *pumila* Grun.
G. intricatum v. *vibrio* (Ehr.) Cleve
G. lanceolatum Ag.
G. longiceps Ehr. v. *longiceps*
G. longiceps v. *subclavata* Grun.
G. longiceps v. *subclavata* f. *gracilis* Hust.
G. olivaceum (Lyngb.) Desm. v. *olivaceum*
G. olivaceum v. *calcarea* (Cleve) van Heurck
G. parvulum (Kütz.) Kütz. v. *parvulum*
G. parvulum v. *micropus* (Kütz.) Cleve
G. sphaerophorum Ehr.
G. tergestinum (Grun.) Fricke
Gyrosigma acuminatum (Kütz.) Rab.
Meridion circulare (Grev.) Ag.
M. circulare v. *constricta* (Ralfs) van Heurck
Navicula amphibola Cleve
N. bacillum Ehr.
N. cryptocephala Kütz. v. *cryptocephala*
N. cryptocephala v. *veneta* (Kütz.) Rab.
N. gracilis Ehr.
N. menisculus Schumann
N. pupula Kütz. v. *pupula*
N. pupula v. *capitata* (Hust.) Hust.
N. pupula v. *elliptica* Hust.
N. pupula v. *rectangularis* (Greg.) Cleve
N. radiosa Kütz.
N. radiosa v. *subrostrata* Cleve
N. rhyncocephala Kütz.
N. rotaeana (Rab.) Grun.
Neidium iridis f. *vernalis* Reichelt
N. productum (W. Smith) Cleve
Nitzschia acicularis (Kütz.) W. Smith
N. acuta Cleve
N. amphibia Grun.
N. angustata v. *acuta* Grun.
N. dissipata (Kütz.) Grun.
N. hantzschiana Rab.
N. linearis W. Smith
N. palea (Kütz.) W. Smith
N. sublinearis Hust.
N. thermalis (Ehr.) Auersw.
Pinnularia appendiculata (Ag.) Cleve
P. divergens W. Smith
P. gibba Ehr. v. *gibba*
P. gibba v. *linearis* Hust.
P. gibba f. *subundulata* A. Mayer
P. interrupta W. Smith
P. mesolepta (Ehr.) W. Smith
P. microstauron (Ehr.) Cleve
P. molaris (Grun.) Cleve
P. viridis v. *sudetica* (Hilse) Hust.
Stauroneis anceps Ehr. f. *anceps*
S. anceps f. *linearis* (Rab.) Cleve
S. legumen (Ehr.) Kütz.
S. phoenicenteron (Nitzsch.) Ehr.
S. smithii Grun.
Surirella linearis W. Smith v. *linearis*
S. linearis v. *constricta* Grun.
Synedra actinastroides Lemm.
(Syn. *Nitzschia actinastroides* (Lemm.) van Goor)
S. acus Kütz. *acus*
S. acus v. *radians* (Kütz.) Hust.
S. rumpens Kütz.
S. ulna (Nitz.) Ehr. v. *ulna*
S. ulna v. *danica* (Kütz.) Grun.
Tabellaria fenestrata (Lyngb.) Kütz.
T. flocculosa (Roth) Kütz.

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